THE OUTLINE OF SCIENCE

J. ARTHUR THOMSON

TYPES OF INSECTIVOROUS PLANTS

1. Venus Fly-trap (*Dionæa muscipula*) of the Carolinas: a fly which has touched one of the sensitive hairs on the upper surface of the leaf is caught by the two halves of the blade snapping together. 2. A true Pitcher Plant (*Nepenthes phyllamphora*) of Cochin-China: in the fluid contained in the pitchers, which are transformed leaf-tips, insects are drowned and digested. 3. An American Pitcher Plant (*Sarracenia flava*): the leaves form pitchers containing fluid, in which insects are drowned. 4. Butterwort (*Pinguicula vulgaris*), a British moorland plant which catches flies in the sticky secretion of glands on the leaf. 5. A South African Sundew (*Drosera cistiflora*) with leaves on the stem. 6. The Common Sundew of Britain (*Drosera rotundifolia*) with a rosette of basal leaves. The Sundews catch insects in the sticky secretion of the leaf glands or tentacles, which then fold over their prey. The plants are artificially grouped.

THE OUTLINE OF SCIENCE

A PLAIN STORY SIMPLY TOLD

EDITED BY

J. ARTHUR THOMSON

REGIUS PROFESSOR OF NATURAL HISTORY IN THE UNIVERSITY OF ABERDEEN

WITH OVER 800 ILLUSTRATIONS

OF WHICH ABOUT 40 ARE IN COLOUR

IN FOUR VOLUMES

★ ★ ★

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The Outline of Science

XVI

PSYCHIC SCIENCE

By Sir Oliver Lodge

PSYCHIC SCIENCE

By Sir Oliver Lodge

IN the long evolution of humanity, we trace, first, the gradual emergence of the organic from the inorganic, the utilisation of highly complex chemical compounds for the formation and purposes of life, and then the gradual rise of living things in the scale of existence, until at a certain stage the rudiments of mind and consciousness begin to make their appearance. At some unknown time after this, must have arisen the power of choice and knowledge of good and evil, which may be regarded as the most definitely human characteristic. Then humanity, too, went on rising in the scale, until it blossomed and bore fruit in the creations of Art, the discoveries of Science, and in works of genius.

Nor is development likely to stop there. Hitherto we have known life and mind as utilising the properties of matter, but some of us are beginning to suspect that these psychical entities are able to utilise the properties of the Ether too—that intangible and elusive medium which fills all space; and if that turn out to be so, we know that this vehicle or medium is much more perfect, less obstructive, and more likely to be permanent, than any form of ordinary matter can be. For in such a medium as ether, there is no wearing out, no decay, no waste or dissipation of energy, such as are inevitable when work is done by ponderable and molecularly constituted matter—that matter about which chemists and natural philosophers have ascertained so many and such

fascinating qualities. Physicists, chemists, and biologists have arrived at a point in the analysis of matter which opens up a vista of apparently illimitable scope. Our existing scientific knowledge places no ban on supernormal phenomena; rather it suggests the probability of discoveries in quite novel directions. Any possible utilisation of the ether, however, by discarnate intelligences must be left as a problem for the future. What appears to be certain is that life and mind require for their manifestation and terrestrial development some form of "material" in the broadest sense, and that there is certainly an interaction between mind and earthly matter.

Statement of the Position

The two branches of knowledge, the study of Mind and the study of Matter, have usually been dealt with separately; and the facts have been scrutinised by different investigators—the psychologists and the physicists. The time is coming when the study of these two apparently separate entities must be combined; for it has always been a puzzle how there can be any relation or interaction between two such apparently diverse things as matter and mind.

The normal facts of their interaction are so familiar that it needs an effort to pick them out with due discrimination, and to present the outstanding problem in all its clearness. A philosopher is aware of the difficulty; and most systems of philosophy have been attempts to solve the mystery and formulate the principles underlying the universe as a whole. But by science in its narrow sense such unification has not as yet been attempted. Physical science deals mainly with matter, and so far as it touches on mind it assumes that mind acts, and can only act, in connection with, or in relation to, or as a development of, matter. The science of psychology, on the other hand, aims at treating of all the normal processes and interrelations of mind, and describes its use of the organs of the body, both for receiving and trans-

mitting impressions, without attempting, or at least without succeeding, in explaining the transition from mechanical vibration to sensation and emotion, or vice versa.

But there are certain asserted facts, now receiving growing attention, which on the surface suggest that mind may possibly exist apart from matter; that, though its manifestations may be, its activities are not, wholly limited to material organs; that mind and matter are in fact not inseparable, and that perhaps matter may be replaced by an etherial vehicle, which would elude our present senses.

There may be some doubt as to what these asserted facts precisely are; but, in so far as they represent reality, it becomes necessary to examine their validity and relevancy, to determine whether the suspicion of independent mental action is justified, and generally to seek to evolve a theory of mental activities beyond those known and familiar. In this way investigators may hope to ascertain whether the facts do really establish an independent and persistent existence for mind apart from its temporary bodily mechanism. So we may summarise and say that to ascertain the real nature of the connection between mind and matter, and the possibilities which underlie their connection—whether those possibilities are generally recognised or not, and even if they lead us into strange and unusual regions of inquiry—is the object of Psychic Science.

§ 1

Psychical Research

The facts which need to be examined have long been known to groups of people here and there from the earliest times, but only of late years—say three-quarters of a century at most—have they been taken seriously by more than one or two individuals, and critically and responsibly and corporately examined, without prejudice and without superstition.

Much had been done previously in the observation and collection of facts, but in 1882 a new Society was founded in London for their special study, along lines as far as possible similar to those which had conduced to the astonishing progress of physical science. And with the birth of this Society (the Society for Psychical Research, or the S.P.R.) Psychic Science may be said to have entered upon a more stable career. The Society has published thirty-two volumes of *Proceedings* and twenty of its *Journal;* amongst its presidents and honorary members there are illustrious names; and Sir A. J. Balfour, the President in 1893, at the end of his Address quite truly implied that the Society had already shown, "not as a matter of speculation or conjecture, but as a matter of ascertained fact, that there are things in heaven and earth not hitherto dreamed of in our scientific philosophy."

To mention the names of the pioneers, and to trace the history of their laborious effort to attain truth, would take up space that may be more usefully devoted to a setting forth of the main phenomena which had to be examined and either rejected as fictions or established as facts. So long as there are legitimate differences of opinion as to the nature of these phenomena, it will be best not to dogmatise nor attempt to sustain a thesis in favour of some and against others, but only to summarise the phenomena now familiar to most people—at least as folklore stories—and to indicate, as far as may be, some means by which it may be hoped that these odd occurrences can be rationalised and understood. We must proceed on the well-tried hope and expectation that everything in the universe, however apparently bizarre, is intelligible to the mind when it is sufficiently well known. Mystery and superstition belong to ignorance; they enshroud tracts which lie in the dark, outside the civilised and cultivated region. An effort is required to deal with such phenomena at all, even if they turn out to be facts; for, without some link or clue with which to connect facts together, they are difficult of apprehension, and they can hardly be said to conform

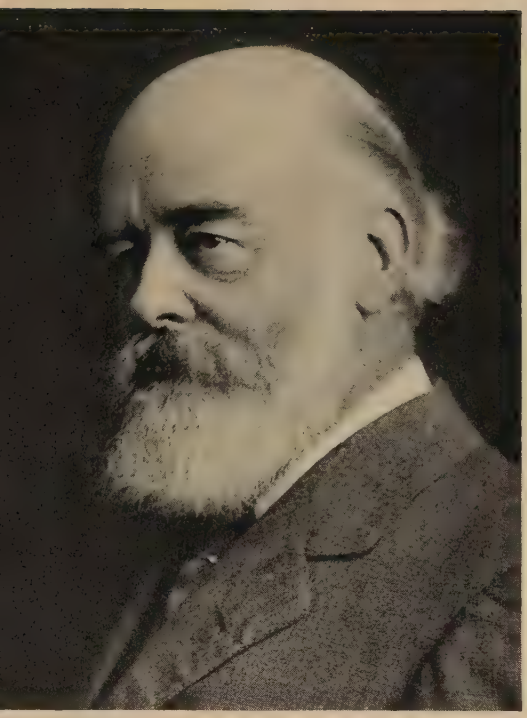


Photo: Russell.

SIR OLIVER LODGE

President of the Society for Psychical Research, 1901, 1902, 1903.

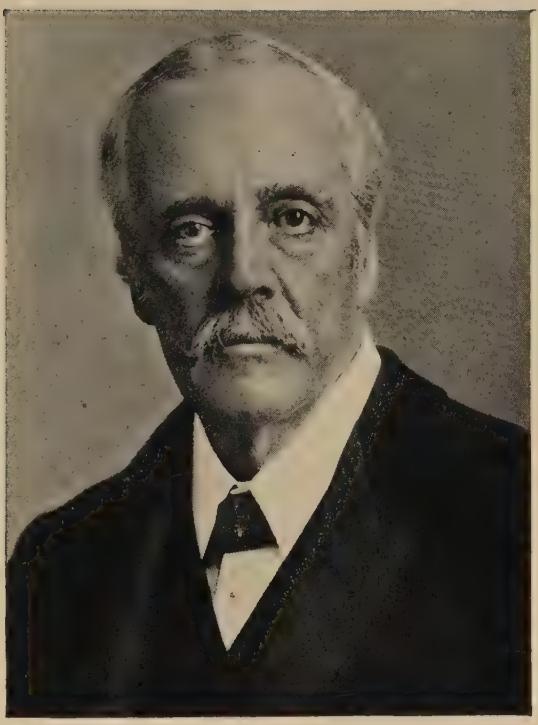


Photo: J. Russell & Sons.

RT. HON. LORD BALFOUR, K.G.

President of the Society for Psychical Research, 1893.

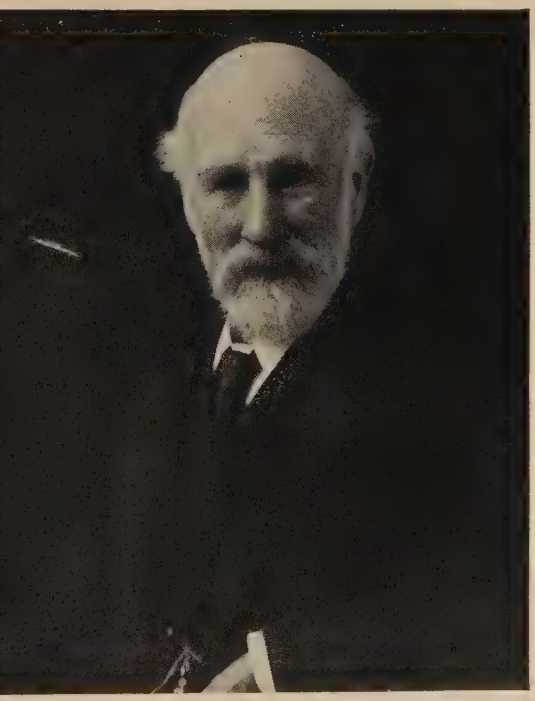


Photo: Elliott & Fry, Ltd.

SIR WILLIAM BARRETT

One of the founders of the Society for Psychical Research and observer of many of the facts which have established telepathy.

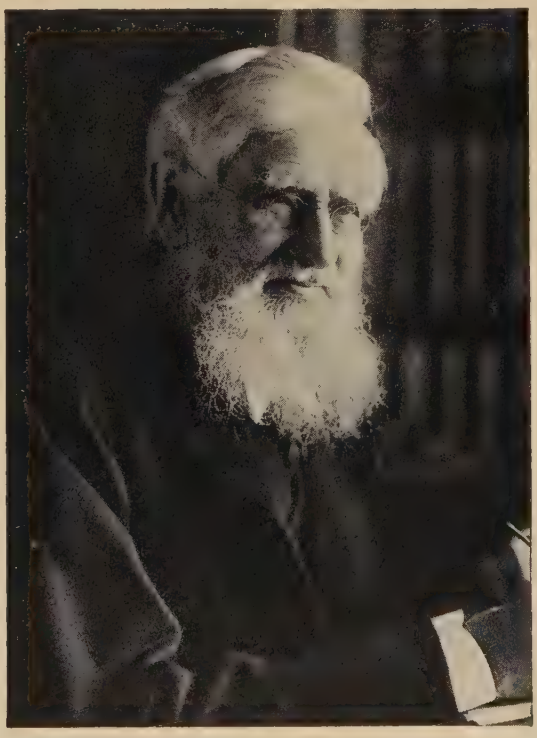


Photo: Elliott & Fry, Ltd.

ALFRED RUSSEL WALLACE

The eminent Naturalist, who became a convinced Spiritualist.

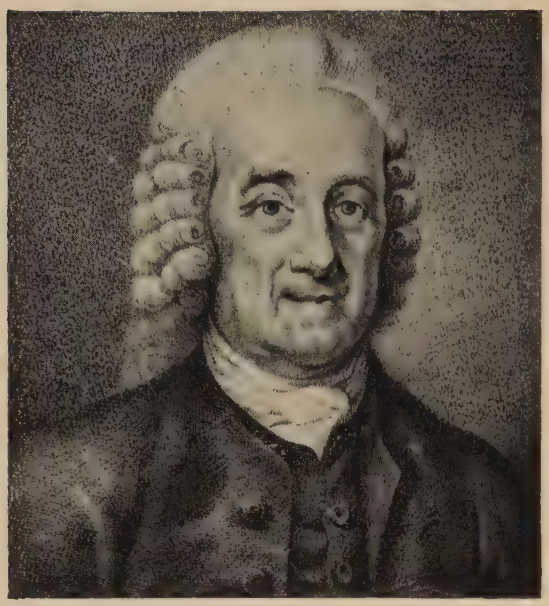


Photo: Rischgitz Collection.

EMMANUEL SWEDENBORG

Natural Philosopher and Mystic.

Photo: Rischgitz Collection.

DANIEL DUNGLAS HOME (1833–1886)

One of the most powerful of modern mediums.

Reproduced by courtesy of the Editor of "Light."

MRS. PIPER

A noted American medium brought to the notice of the English Society by Prof. Wm. James, and investigated by the Society for a quarter of a century.

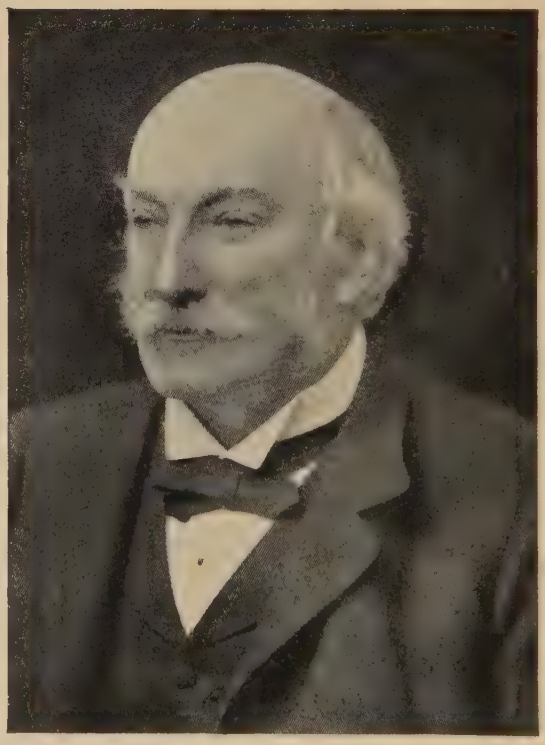


Photo: Russell, London.

LORD RAYLEIGH

The great Mathematical Physicist, President of the Society for Psychical Research, 1919.

to the requirements of science. There must be system and orderly arrangement, before *disjecta membra* can be assimilated and incorporated into the main body of organised knowledge.

§ 2

Firstfruits of the Inquiry

One of the firstfruits of the labours of the S.P.R., or rather of the pioneers who founded it, was the discovery of "telepathy," or thought-transference between mind and mind without the use apparently of *any of the known organs of sense.* It was found by careful experiment that an idea or visual image, or other familiar notion, could be conveyed to another person, provided he possessed the faculty of receptivity, although that person was screened from all normal channels of communication. Experiments of this kind were at first conducted in the same room, usually with trivial things like portable objects and diagrams and numbers—stringent precautions being taken, by the use of opaque screens without dependence on the completeness of blindfolding, that normal means of acquiring information about the diagrams or objects were excluded. Experiments of this kind will be found in most of the earlier volumes of the *Proceedings of the S.P.R.*

Similar or slightly modified experiments were afterwards extended to a considerable distance; and still, between so to speak "attuned" persons, the amount of correspondence was found to be beyond chance. The evidence is bulky, and perhaps rather tedious, but the establishment of such a faculty is of prime importance, and is worth the labour, for manifestly it begins the demonstration of the possible independence and separation of mind from its ordinarily used methods of communication. The voice and the hand, the ear and the eye, are no longer the only transmitters and receivers of mental impressions.

Several series of experiments in thought-transference in the

same room will be found in the early volumes of the *Proceedings of the S.P.R.*, and a few of the diagrams looked at by the "agent" and simultaneously drawn by the blindfolded and screened "percipient" in these experiments can be reproduced here; these being selected as successful instances. But from the point of view of evidence the whole series must be studied, and chance eliminated.

Perhaps the most interesting of recent experiments on this subject are those conducted by Professor Gilbert Murray in his own family, where the thing transferred was not a diagram or anything objective or visible at all, but an event or scene silently thought of by one of those present. For instance, these successful items from the *Proceedings of the S.P.R.*, vol. xxix:

Agent silently thinks of:

"Alister and [Malcolm] MacDonald running along the platform at Liverpool Street, and trying to catch the train just going out";

while, after a pause, *Percipient says aloud:*

"Something to do with a railway station. I should say it was rather a crowd at a big railway station, and two little boys running along in the crowd. I should guess Basil."

. . . . . .

As another instance may be quoted this one.

Subject thought of by Agent:

'Belgian Baron getting out of train at Savanarilla with us, and walking across the sandy track and seeing the new train come in."

Statement by Percipient:

"Man getting out of a train and looking for something. I don't know if he's looking for another train to come. I think it is a sort of dry hot sort of place. I get him with a faint impression of waxed moustache—a sort of foreign person —but I can't get more."

. . . . . .

And another, an ambitious and rather remarkably successful and dramatic attempt, may also be here cited.

Subject set by Agent:

"A scene in a story by Strindberg. A man and woman in a lighthouse, the man lying fallen on the floor, and the woman bending over him, looking at him and hoping that he is dead."

Percipient's guess:

"A horrid atmosphere, full of hatred and discomfort. A book, not real life. A book I have not read. Not Russian, not Italian, but foreign. I cannot get it. . . . There is a round tower, a man and woman in a round tower: but it is not Maeterlinck. Not like him. I should guess it was Strindberg. The woman is bending over the man and hating him, hoping he is dead."

. . . . . .

Assuming that the experiments were fairly conducted, we are driven to suppose either that one brain acts on another brain, through the interaction perhaps of some hypothetical and unknown ether waves; or else that the phenomenon is a purely psychic one, and that the impression is transmitted direct from mind to mind without any necessary connection of a physical nature between brain and brain. Or, indeed, a third hypothesis, which possibly may be gaining adherents, viz. that a third intelligence, not one generally recognised, is in operation, and is conveying information from the mind of A, or agent, to the mind of B, or percipient; in fact, that the connection is not direct between A and B at all, but is managed by an invisible and intangible operator C.

This may sound an absurd surmise, and one that need not be made in connection with such instances as these. But it is not an easy matter, anyhow, to explain the conveyance of an idea by purely psychic means, or even to attempt clearly to formulate such an operation; hence any working hypothesis which can be suggested may have to be tested and tried to see if it will work.

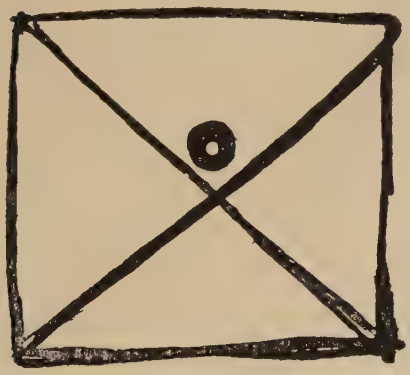
At least the bare possibility of messenger-communication will help to prevent too easy and certain a conviction about the existence of wholly unproven "brain-waves." The testing of working hypotheses is a commonplace procedure in science. Such hypotheses do no harm if they are lightly held, and if a key is not unduly pressed into keyholes which it does not fit. Some good judges think that a mysterious non-vocal method of intercommunication may have been inherited from an animal and savage ancestry, though it has now become almost overlaid and suppressed by civilisation and disuse.

§ 3

Concerning Citation of Illustrative Examples

If instances or samples of each or of some of the things which are said to occur are quoted in this article, it can only be by way of illustration, not as evidence of fact. For to give anything like real evidence, all manner of details of time and place must be supplied, together with confirmatory testimony and extracts from any relevant documents that may be available. The securing of evidence is a troublesome business, involving the interviewing of witnesses, the examining of places, the obtaining of signed statements, and generally the securing of details which, however instructive and necessary, are laborious to collect and bulky to record. Recorded testimony of this kind must be sought in the *Proceedings* and *Journal* of a scientific society and other serious publications. If it be complained they are not easy reading, that is a disadvantage they share with the *Proceedings* of learned societies in general. They do not aim at being easy, they aim at being exact and trustworthy. So the samples here and there cited below, though based upon actual statements, may be taken as mere assertions, or at best as illustrations or types of what has to be substantiated, or else criticised and demolished, elsewhere.

The Agent thinks of or draws an object of some kind and concentrates his thoughts upon it. The other person—the Percipient—tries to keep a blank mind as far as possible. After an interval the Percipient describes or draws whatever image has come into his or her mind.



AGENT'S ORIGINAL DRAWING

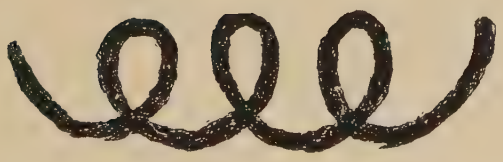
REPRODUCTION BY PERCIPIENT

This was one of many obtained by the Author in Carinthia with an Austrian lady as Percipient.

ORIGINAL DRAWING BY AGENT

REPRODUCTION BY BLINDFOLDED PERCIPIENT

These and the following experiments were made in Liverpool by Mr. Guthrie, with the aid of Mr. Birchall and others, who were strangers to the Percipient.



ORIGINAL DRAWING BY AGENT

REPRODUCTION BY PERCIPIENT

The Percipient, in this case, said she seemed to see a lot of rings, as if they were moving, and that she could not get them steadily before her eyes.

ORIGINAL DRAWING
BY AGENT

REPRODUCTION BY
PERCIPIENT

ORIGINAL DRAWING BY AGENT

REPRODUCTION BY PERCIPIENT

Percipient said, almost directly, "Are you thinking of the bottom of the sea, with shells or fishes?" and then, "Is it a snail or fish?"—and then drew as above.

Hallucinations or Apparitions

After experimental telepathy was fairly established, a spontaneous variety such as had long been suspected and was the basis for innumerable stories, in history as well as in fiction, was examined and brought to book. This spontaneous kind of telepathy—analogous to spontaneous radioactivity as contrasted with the experimental excitation of X-rays—is held responsible for many apparitions or hallucinations or phantoms, whether of the living or of the dead, especially the appearance of persons then being subjected to a strong emotion, or some calamity or accident, or in imminent prospect of death. The difference between this and the experimental form of thought-transference is that, whereas in an experiment the conscious attention and will-power of the agent is riveted on achievement of the result—though it has hardly been proved that conscious effort is really effective—in the spontaneous class it is the unconscious mind which must be assumed to be operative, for the impression is transmitted without conscious intention and without knowledge of the supposed agent that it has been done. Thus, let one whom we may tentatively and hypothetically regard as the agent be suffering shipwreck, or be in danger from fire; his mental constitution may be supposed so upheaved that any latent power of telepathic or sympathetic communication is evoked, and translates itself into an impression in the mind of some distant relative or friend, with such vividness that the circumstances of the person in danger are presented to the friend's imagination as if they had veritably been conveyed through the sense of sight or of hearing. A phantom in dripping clothes, or a voice in tones of distress, are as it were "seen" or "heard" by the one whom we may regard as the percipient; not with the bodily eyes or ears, but with the mind: though the mental impression may readily be interpreted as an objective reality, not as of a person at a distance but as of a person close by, so as to be accepted as within reasonable reach of the organs of sense.

As when a boy killed by a crash from the air is both seen and heard, almost immediately afterwards, by another officer sitting in the camp, and hailed and spoken to; surprise being expressed that his long journey was so soon over. The figure, which exhibited identifying details of costume, responds and goes out. In the evening the officer learns that this same youth, whom he knew intimately, had been killed by an accident on the way to his destination, at just about the time of his appearance. A much fuller account of this occurrence is in the *Journal of the S.P.R.* for June, 1919. But really instances of this kind are innumerable, and are often narrated in biographies.

The voice of Rochester heard by Jane Eyre at an impossible distance could not be attributed to a hyper-acute sense of hearing; if it occurred in reality it would have to be attributed to a telepathic or sympathetic connection between, shall we say, kindred souls; for it is represented as a reciprocal and not a one-sided experience. Mrs. Gaskell heard Charlotte Brontë say that it was based on an incident which had really happened.[1]

Few families are without some such story in their archives; and all difficulties about the physical appearance of any real phantom, the dripping clothes for instance, the accompanying horse, or any wild scene generally—which cannot be thought of as an objective present reality, even if the phantom itself could so be regarded—all difficulties of this kind vanish or are reduced to insignificance when once it is realised that the whole impression is a mental one, and that the surprised percipient has automatically constructed not only the phantom itself, but a number of accessory features too, as mental imagery appropriate to and aroused by the purely mental shock or stimulus which, through his unsuspected receptive power, he has been privileged to receive.

Such cases are far too numerous for chance coincidences to explain—a fact which a most carefully conducted and hypercritical census of inquiry has established. The sensible thing for

[1] *Life*, p. 445.

those who are out for unprejudiced truth is to accept the demonstrated fact and see if they can devise some line of explanation better than the telepathic one. For because telepathy of some kind is a plausible explanation, it does not follow that it is the true one in every case. Our aim is not to rest satisfied with what may superficially seem probable, but to ascertain what is true.

As an example of a phantasm of the living, we may take the case of a mother with a sailor son at work in the Pacific. She dreams or has a vision of him standing by her bedside in dripping clothes, accepts the omen, and subsequently mourns him as dead. Six months later he turns up alive and well; but, gradually, in response to inquiries, admits that he had run the risk of being drowned, for he had fallen from a mast into the water, and had only with difficulty been rescued. And it is maintained that the date of the accident agrees well enough with the phantasmal appearance.

Mrs. Arthur Severn being awakened by an imaginary blow on the mouth, at the same time as her husband sailing on Lake Coniston before breakfast is struck in the mouth by the swing round of the tiller, is a well-authenticated case of spontaneous and unconscious telepathy.

§ 4

Visions or Apparitions of the Dead

A further step may have ultimately to be taken. Not only are phantasms of the living experienced, we find also clear records of phantoms of the dead. The two classes merge into one another, for the moment of death may be uncertain, and some latitude for delayed impression must be allowed; but undoubtedly appearances of dead people have occurred, and whether these also are to be attributed to a telepathic impression, received from a discarnate agent, remains an open question. On the whole

the hypothesis of telepathy from the dead is regarded favourably by some of those competent to judge.

The standard classical instance of such an occurrence, as narrated by the poets, is the appearance of the drowned Ceyx to his beloved wife Alcyone, and her consequent veridical conviction of his fate. The story is beautifully told, with full circumstance and vividness, in the eleventh book of Ovid's *Metamorphoses*. But it is noticeable that in this instance Ceyx had been dead for some days when the phantom appears, and the poet takes it to be a messenger from the gods, assuming the form and voice of the dead man in order to convince Alcyone of the truth.

And yet telepathy, though wide in its range, does not cover all the ground. It has to be stretched considerably in order to account for many apparitions, and especially for what is called the "fixed local" ghost, that is to say, an apparition said to be encountered in association with certain houses or places with the reputation of being haunted; any stranger being said to be able to see the apparition at suitable times, even if he were ignorant of the legend and unacquainted with the traditional haunting.

The first thing is to make sure that the facts are as described, and that such persistent haunting is a reality. It seems wisest to preserve an open mind on that subject; for the evidence, though noteworthy, is not yet considered as crucial as that for the other class of phantasms—the class more readily conceived of as due to transmitted mental impression. There appears to be a certain objectivity about this fixed local ghost: there seems no obvious agent to whom to attribute a telepathic impulse; and besides, the things the ghost is sometimes said to do are hardly consistent with a mere mental impression—though certainly the hypothesis of a vivid dream on the part of the percipient must be allowed all the benefit of any doubt there may be, and the burden of proof that there is anything objective in the experi-

ence must rest upon the narrator. No need to adduce any examples: ghost stories of this class are almost too well known; they are difficult to remember in detail, though absurdly easy to invent.

Is there any rational hypothesis that can be thrown out for the explication of such phantoms as these, provided they establish themselves as facts? Does the possible independence of or unusual connection between mind and matter—the occasional freedom of the mind from the body—at all assist in such explication? On the whole and tentatively it does, along one or two channels.

Clairvoyance or Lucidity

First along the line of clairvoyance or lucidity. A critical examination of mediumistic powers has shown that occasionally they can extract information, not only from people's minds, by what we assume to be a process of telepathy—whatever that is—but also occasionally from commonplace objects. That they can decipher, for instance, what is in a sealed letter or packet, or read part of a page of a closed book. This "reading with the pit of the stomach," as it was long ago called, or reading with the top of the head, or with the fingers or some other part of the body, has sometimes been attributed to hyperæsthesia, as if parts of the skin not usually sensitive to visual impression become so under exceptional conditions, or as if the sense of sight became incredibly penetrating and efficient. The difficulties about such a semi-physical theory are insuperable, and it is better to affix the term clairvoyance or lucidity to the phenomenon, without any attempt at explanation in the first instance, and continue to scrutinise intelligently the facts.

A well-known instance, detailed by the great philosopher Kant, is when Swedenborg was aware of a fire in Stockholm, 200 miles away, and rose perturbed from a dinner party, remaining disquieted for an hour or two; until his anxiety subsided, and he was able to assure himself and his friends that the fire had been

got under, and that it had been extinguished before it had reached his own home, though it had been dangerously near it. All which, in a day or two, was verified.

As for the apparent reading of distant books, an appropriate Biblical text is sometimes given by chapter and verse; but that may be thought due to memory. It is difficult to attribute to the memory of a youth killed in the war the precise statement that a comforting message to his mother will be found near the bottom of page 77 of the third book on the shelf where his school books are kept, in a house the medium has never been in. And yet things akin to this are contained among the so-called "book-tests" which of late have been received and published.[1]

The actuality of real clairvoyance, as distinct from any kind of telepathy, is not an easy thing to test; for if the knowledge has existed in any mind whatever, telepathy or mind-reading may be the simplest or at least a possible hypothesis; and, furthermore, if a thing is in no mind at all, and never has been, it does really seem as if it were difficult or perhaps impossible for any medium to get hold of it. On the other hand, if a packet is really known to a deceased person, the information can sometimes be obtained. As an illustration of the kind of thing expected from a sealed packet the fictional instance told by Mr. E. F. Benson in his novel *Up and Down* may be cited, for it is evidently modified from some real experience and represents in a more or less guarded and imaginative manner something of the kind that occasionally happens.

In the reading of sealed packets and the like, there are often failures. But failures—like negative results generally—prove hardly anything; moreover, they may be due to natural lapse of memory. The *theme* of a posthumous message or written sentence may be remembered, but it may be impossible to recall at will the exact words in which it was expressed. This happened in a famous instance, when the late F. W. H. Myers failed to

[1] As, for instance, in Lady Glenconner's *Earthen Vessel.*

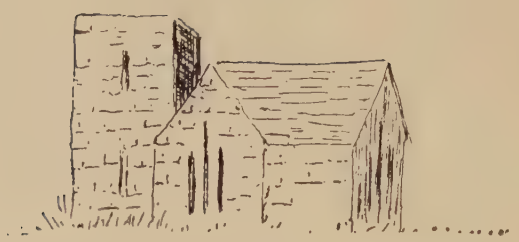
EXPERIMENTS AT A DISTANCE

In order to ascertain whether distance was any obstacle to telepathy, two ladies, members of the Society for Psychical Research, who knew that they were often in telepathic rapport, decided to keep a record of what one perceived and what the other saw, at a certain time each day, when they were some hundreds of miles apart, their descriptions being sent to the office of the Society there to be compared. Seldom was it a scene consciously attended to and "willed" that was thus transferred, but constantly some other scene from the immediate neighbourhood of the one was transferred to the other.

The illustration below and that on the following page must serve here as a sample of a large number of recorded observations.

PHOTOGRAPH BY MISS MILES OF SILK FACTORY AT MALMESBURY IN WILTSHIRE

The Percipient, Miss Ramsden, had never been to Malmesbury, and was at the time in Scotland when she drew and described what she thought was in Miss Miles's neighbourhood as follows: "A waterfall; it looks artificial because it is very broad and regular and not more than two or three feet high; it might be a millstream. Then I begin to see a house—a farmhouse?—with a very tall poplar near it. There is rising ground—not to be called hills—and young plantations." Then she drew this diagram.



THIS IS WHAT MISS RAMSDEN, IN SCOTLAND, DREW: ADDING, "SOMETHING IS WANTING, AS IT SEEMED BIGGER AND MORE IMPOSING"

HENBURY CHURCH

AND THIS IS WHAT MISS MILES, IN THE SOUTH, PHOTOGRAPHED AS A PLACE SHE HAD BEEN VISITING.

repeat the sentence which he had written inside an envelope and handed to me twelve years before his death. Memory of the theme alone was quite insufficient for this particular kind of test. The result has to be counted as a complete failure.

Psychometry

Moreover, even if successful, the evidence for survival from a deciphered posthumous letter or package would be inconclusive —much more inconclusive than people are apt to suppose. For the contents of packets, or the history of relics belonging to a deceased or distant person, have frequently been said to be deciphered by a medium who handles them—the process is known as psychometry—just as the pages of closed books, even while still in a distant library, have been read. These things do not seem inaccessible to this strange faculty of lucidity; and the appearance is as if the actual objects were able to produce an impression on some mind.

At any rate, that is the kind of supposition which underlies the hypothetical or tentative explanation of the fixed local variety of ghost. It is supposed that a sort of phonographic or photographic record has been left on, say, the walls or furniture of a room in which a tragedy has occurred, and that this latent impression can be psychometrised and disinterred from oblivion, by a person possessing the required faculty, with sufficient vividness to enable that person automatically to reconstruct the scene and describe the figures taking part in the psychical drama, as if they were again present and dreamily active.

Another alternative is to suppose that the deceased actors in the drama are themselves liable to dream vivid recurrent dreams of the past, and that these dreams act telepathically on the mind of a sensitive. It seems as if this kind of thing could happen between living people. A literary instance of a very vivid and complete experience of this kind—a kind of dream experience

not altogether unknown to people now living—is the remarkable story of *Peter Ibbetson* by George du Maurier.

§ 5

Materialisations

But there is another and still more puzzling line of explanation, which some are inclined to adopt, viz. the hypothesis that not only can matter act on mind, but that mind can act on matter without the intervention of the muscles, can extrude a certain kind of organic material from the body of a so-called physical medium, and can collect and form it into an actual presentation of form or features such as is technically known as materialisation. A physical phenomenon of this extraordinary kind requires exceptionally strong and cogent evidence, but it is one of the phenomena that are vigorously asserted to have occurred under favourable conditions; and some eminent Continental physiologists have, against their will, been convinced of the reality of the bare occurrence. It is said to take a good deal of energy, and, therefore, to be assisted by the presence of a fair number of people—a circumstance which evidently makes strict investigation more difficult. Moreover, it requires specific mediumship of a certain strong, even though low, kind—a kind which cannot always be depended on as forthcoming at every date when a competent investigator is ready and willing to examine unlikely things of this sort.

Fortunately, in the past, the combination of a strong medium and a competent investigator has occurred, and has given us at least a record of a remarkable series of occurrences of this kind. And, again, to-day there are those who are able to testify to actual physical temporary materialisations, which can sometimes be seen, sometimes handled, sometimes moulded in plaster or paraffin, and more often photographed.

Furthermore, the material or semi-material fluid or substance or plasma is said to be able to move objects with consid-

erable force, thus bringing about the phenomenon which has been named "telekinesis," or movement of objects without apparent or normal contact.

If this faculty of materialisation is established, however it be accounted for, the application to some varieties of ghostly apparition is obvious. Something visible, and occasionally tangible, may be really *there*.

But it must be clearly stated that several of the Continental observers who have most successfully and thoroughly scrutinised this materialising and telekinetic phase of mediumistic activity are very loth to entertain the spiritistic hypothesis in any form; these scientific investigators prefer to regard it as an unexplained power of the medium's own organism, when in an unconscious or hypnotic state. They have to assume a power of rearranging the molecules of an extruded bodily substance, known as ectoplasm, which emanates from a medium's body, so as to cause it to simulate the appearance of human bodies or parts of bodies. And they have further to assume the possibility of its exerting considerable force on objects in the neighbourhood.

Psychic Photography

However this may be, physical phenomena are among the things requiring investigation by psychic science; and one of the commonest forms at the present time is psychic photography. Some mediums are said to have the power of so influencing the photographic process that when, say, a widower or a bereaved parent, arriving quite anonymously, is photographed, a shadowy extra representing his deceased wife or son is sometimes obtained too. Whether these so-called "extras," if genuinely produced by a supernormal process, are "psychographed" on to the plate itself independently of the camera—though perhaps requiring exposure to light to bring them out,—or whether there is something in front of the camera which is optically focussed upon the plate during the exposure given for the purpose of photo

graphing people present in the ordinary way, or whether both of these things may occur at different times, is a matter not yet fully settled, even among believers in the facts. It may be as easy to supernormal operators to manipulate the chemicals in a film as to manipulate the plasma into a face; one cannot say which is the easier hypothesis, when both seem equally impossible.

Direct Writing and Speaking

Another strange phenomenon, which must be regarded as akin to incipient materialisation, is the comparatively well-evidenced phenomenon of direct speaking or direct writing.

What is called automatic writing, when the pen is held by an ordinary person and appears to write without conscious volition, is a purely psychic phenomenon; for there is no question that the muscles of the writer are used, any more than there is a question that the voice of the medium is used in ordinary trance utterance. In these cases it is the substance of the message that alone needs consideration to establish any supernormal faculty. But there are rather exceptional mediums in whose presence pencils are said to write without being touched; and others in whose presence, under suitable conditions, voices are said to be heard which do not emanate from the throat or larynx or even the neighbourhood of the medium, or of any person present in the flesh. This phenomenon is called "direct" because, not only is the subject-matter dictated in a supernormal manner, but the physical act is accomplished in an inexplicable manner too.

§ 6

Dowsing

On the verge between purely psychical and semi-physical phenomena are such faculties as dowsing and travelling clairvoyance.

The dowsing or water-divining faculty is a very ancient claim, said to be hereditary in families; and, however it be done,

F. W. H. MYERS

The erudite scholar and authority on Psychic Research, President of the Society for Psychical Research, 1900.

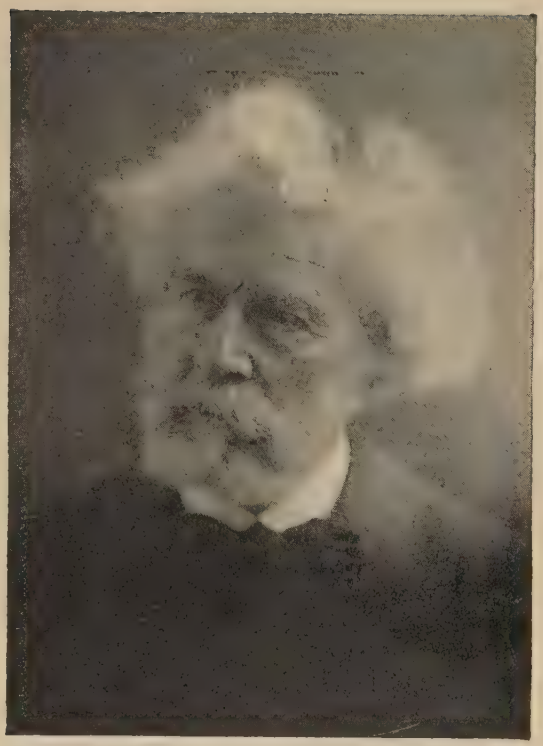
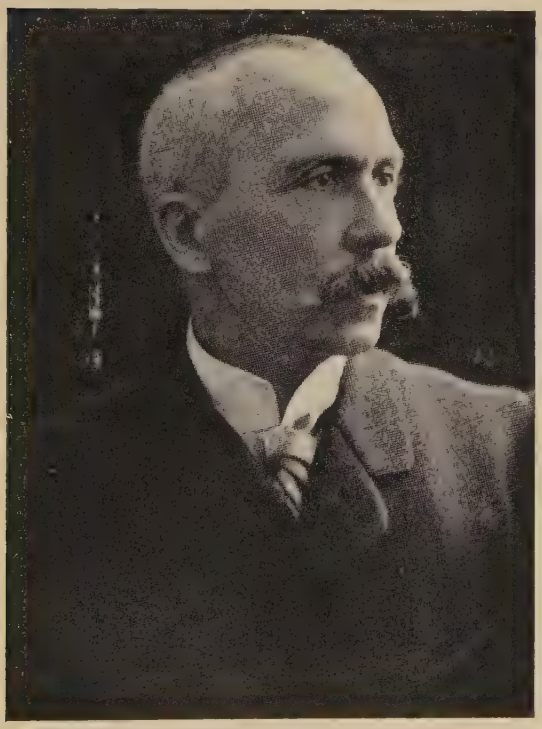


Photo: Henri Manuel.

PROFESSOR FLAMMARION

The eminent French Astronomer, who has recently published the first of four large volumes on psychic science.



PROFESSOR CHARLES RICHET

Professor of Physiology in the University of Paris, President of the Society for Psychical Research, 1905.

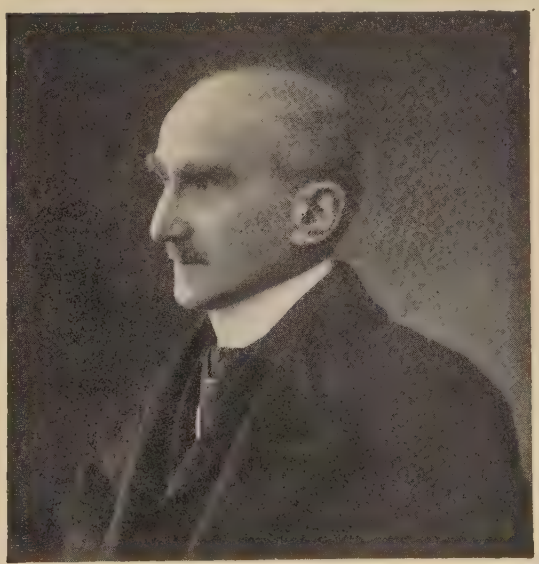


Photo: Henri Manuel.

PROFESSOR BERGSON

The eminent French Philosopher, President of the Society for Psychical Research, 1913.

THE ART OF DOWSING

Mr. W. Stone, describing how he found he possessed the art of dowsing, said: "I felt a peculiar twitching in the rod, and hearing that the rod would turn with anyone who had this feeling, I was determined to stop it if possible, but to my astonishment the rod twisted itself over until it broke in my grasp."

MR. TOMPKINS "DOWSING" IN SOUTH AFRICA

He was originally a farmer in Wiltshire. He was successful in obtaining water for his cattle at three different places on his own farm. Ultimately he became a professional dowser.

it has undoubtedly been found useful. It is as if some faculty of remote ancestors to whom water might be a matter of life and death—a faculty akin to the not yet understood homing instinct of animals—survived among some individuals, even now. The dowser takes a twig in his hands and feels it struggle and turn when he is over the desired kind of water or other mineral. This appears to be a genuine impression on his part, however it may be produced; and the result is that, with people skilled in the art, the finding of springs of water in unlikely and difficult places has actually been accomplished. It is like a form of clairvoyance or lucidity, akin to the finding of hidden objects or the reading of closed books.

Travelling Clairvoyance

Real travelling clairvoyance may take various forms, and is rather liable to be associated with enfeebled bodily condition, as if the link with matter was being loosened or relaxed without being completely broken.

As an example of travelling clairvoyance under pathological conditions we may instance the experience in South Africa narrated by the eminent Professor of Surgery, Sir Alexander Ogston, LL.D., etc., in his book *Reminiscences of Three Campaigns.* During an attack of typhoid he often felt separated from his body, which he then regarded with some loathing, though he felt compelled to enter it from time to time; until gradually he felt his wanderings restricted, at about the time when the attendants began to hope for his recovery.

> In my wanderings there was a strange consciousness that I could see through the walls of the building, though I was aware they were there, and that everything was transparent to my senses. I saw plainly, for instance, a poor R.A.M.C. surgeon, of whose existence I had not known, and who was in quite another part of the hospital, grow very ill and scream and die; I saw them cover his corpse

> and carry him softly out in shoeless feet, quietly and surreptitiously, lest we should know that he had died, and the next night—I thought—take him away to the cemetery. Afterwards, when I told these happenings to the sisters, they informed me that this had happened just as I had fancied. But the name of the poor fellow I never knew.

This kind of experience, with varieties of form, has often been narrated by persons who have been at the point of death and have recovered, or who have awakened out of a deep trance. Such persons have said that they felt physically attached to the body, as by a kind of cord, and were under the impression that if the cord snapped return would be impossible.[1]

Return is indeed often undesired, for the free condition seems much more attractive than the cramped, fettered, and commonplace condition familiar to us in our customary association with an animal-descended body, full of appetites and liable to pain and physical troubles: though, doubtless, the association is for some good and evolutionary purpose.

Travelling clairvoyance is the projection, as it were, of the intelligence out of the body into some distant place, so that it brings back information as to what is there at the time occurring; it is a phenomenon which certainly suggests the separation and independent existence of mind and body, and which also in some exceptional forms suggests an ectoplasmic or other vehicle for the intelligence, while separated from its usual complete organism.

For when the distant vision of the surroundings of an absent person is being attained, by what feels like a visit to a distant place, there are certain rare, so-called reciprocal, cases in which the distant person is aware of the presence of his visitor, who is said to manifest a sort of phantasmal appearance, as if the perception were not wholly subjective, and not limited to one side alone.[2]

[1] Cf. J. A. Hill's *Man is a Spirit*, ch. iv.

[2] A good instance, much too long to quote, is cited in Myers's *Human Personality*, vol. i, p. 682, from vol. vii, p. 41, of the *Proceedings S.P.R.*

Apports

Such joint clairvoyance may perhaps be only a vivid kind of reciprocal telepathy; but there are some asserted instances of what cannot be wholly accounted for by any form of telepathy, in which an actual movement is produced, and some object is displaced and left displaced, or brought from a distance or carried away to another place: this being a variety of the phenomenon known as "apports," which need not be necessarily associated with clairvoyance at all. Things are asserted to happen in a seance as if a far-fetched object, such as a live parrot or a piece of Chinese jade or some rare Egyptian relic made its appearance in the closed and locked room in which a party are assembled, without (so it is said) anyone having brought it in.

That these things sound incredible is obvious; the question is whether anything like them ever occurs, or whether honest testimony that they have occurred, on a given occasion, is merely the result of a conjuring device.

Every kind of deception is not fraudulent. The tricks of a conjurer are deception, but not fraud. Deception is what he is paid for; it might even be regarded as fraudulent if he failed to produce some sort of rabbit out of a hat. It is charitably thought that the subconsciousness of a medium sometimes resorts to deception in order to achieve desired results without any intention of fraud.

Accusation of conscious fraud is a serious thing, and should be held to require substantial proof. Such proof has at times been forthcoming—with legitimate consequences,—but appearances may suggest it without being really convincing; and care should be taken in this as in all other matters connected with an obscure subject. That deception and fraud are both possible is manifest; that they are more probable *a priori* than the phenomena themselves may be admitted; the question is what substratum of truth remains when these *veræ causæ* are effectively allowed for or thoroughly guarded against. It is known in business that

there comes a stage at which continual suspicion or discredit of a reputable personality becomes unreasonable, and foolishly inimical to trade: but there may be differences of opinion as to when that stage is reached.

It is sometimes said that a professional medium, who gets a fee of half a guinea or thereabouts, has a motive to deceive. But an amateur with no pecuniary temptation may also have a motive to deceive—it may have been noticed that money is not everything in this world—and the fact that the temptation in his case is of a more subtle and less generally recognised character tends to ease his task by making him more immune from suspicion. Indeed, if an officer and a gentleman thought it worth while to sacrifice his honour, and to lie with unscrupulous persistent cleverness, there is no telling how far his deception could go: he might deceive even the very elect. Few, if any, deceivers, however, have so far shown sufficient cleverness to evade the suspicion and secure the confidence of a hardened and experienced and trained investigator of the S.P.R. It is thought by many that suspicion and lack of confidence have by that Society been pressed unduly far. Suspicion is the safest attitude—perhaps the only safe one—in the present state of public ignorance and against a background of ingenious plots and conspiracies to waylay and trap the unwary; but it must be admitted that an atmosphere of suspicion and cold aloofness—however wise and needful—does tend to militate against the production of genuine phenomena, and thus to diminish opportunities for rational investigation. For if nothing is produced, there is nothing to examine; and the mere inhibition of phenomena, though safe and prudent, does not enlarge our opportunity for observation and for framing improved theories as to the *modus operandi.*

The giving of some kind of credit, the faith which is the foundation of business enterprise, seems likely to be fruitful here also, in spite of the risk. "Without faith there is no redemption." Without risking something there is no gain.

§ 7

Evidence for Survival

Leaving these puzzling physical phenomena and returning to the more purely psychical demonstrations, we encounter not only evidence of telepathy and of clairvoyance, but of the simulation of personal control, whereby it certainly *appears* as if a deceased person were making use of the medium's organism, to speak and write somewhat as he might have done when he possessed his own physiological mechanism. The trance and the hypnotic states have several points in common, though they are not identical; and whereas in the hypnotic state (so long uncritically and stupidly denied) the patient is more or less amenable to the thoughts and will of the operator, in the trance state the medium is influenced by either a secondary personality or by some form of controlling intelligence (not present in the flesh and sometimes believed to be a discarnate person once resident on the earth), who wishes to take this indirect means of proving his continued existence, and of sending an assurance of help, or a message of abiding affection, to members of his family. Messages of affection, however, are seldom evidential, though through the use of pet names, etc., they have a certain value, provided nothing has been given away by an incautious sitter. Certainly a strenuous effort is made sometimes to give proof of surviving personal identity. All manner of trivial incidents are recalled, and personal peculiarities are emphasised; and, though these things are usually known to someone present, or are afterwards recalled by some near relation, and therefore may be plausibly attributed to telepathy from the living, an effort is evidently being made to show that they are really due to telepathy from the "dead"—though they rather resent the application of that term when they are feeling all the time active and vigorous. The method of demonstration they adopt, when possible, is to mention things which only they knew, in the hope that their friends will

succeed in verifying them, and will accept the evidence as proof of their continued existence.

Sometimes the communications are useful; as when Swedenborg was able to get from the deceased Dutch ambassador, M. Marteville, the location of a secret drawer unknown to the family, in which was a missing document that had been long hunted for fruitlessly by the widow. Verification of the finding of the document, after getting the information, was specially satisfactory in this case, because it was done in the presence of a number of people who happened to be in the deceased's house at the time when Swedenborg arrived to report what he had learned, and to stimulate the final instructed search.[1]

Sometimes the communicators show signs of anxiety and distress, about things they wish to remedy and cannot. As when a soldier, killed at the front, appears to a stranger at a sitting and begs that his kit may be overhauled and certain letters and documents extracted and destroyed, for that they would cause irremediable mischief if seen by his folk at home. How to get this done is forthwith discussed; and at length the communicator suggests the name of a person known to him, in sufficient authority and with sufficient family connection to make it possible that the mission might be accomplished. The sequel is that the message was given, and suitable action taken. It all turned out true; so the vicarious misery which had been legitimately weighing on the mind of the deceased was averted.

Sometimes the natural affection they exhibit takes a form which does happen to be of an evidential character. As when a secret engagement is announced to his family by a deceased soldier, with the name and address of his betrothed, accompanied by the request that when she is found a certain object of remembrance which is still in his unopened kit, unknown to anyone, may be found and given her.[2]

[1] Kant, *Träume eines Geistersehers.*

[2] See Barrett, *On the Threshold of the Unseen*, p. 184.

Moreover, some of the most skilful communicators "on the other side" have taken the trouble to clinch the argument by sending mysterious fragments of references, through several independent mediums in different parts of the world, nearly simultaneously; fragments which are only perceived to have a meaning, and that a personal and identifying one, when they are all collected and compared and seen to fit into each other like the fragments of a puzzle. This is what is called the system of "cross-correspondence." They have also succeeded in showing scholarly knowledge, appropriate to themselves, but beyond the scope of anyone present, and of a grade often edifying to living scholars. It is a great mistake, though one often made, to suppose that only rubbish comes through.

The last-mentioned elaborate devices—how elaborate is only known to painstaking students—cannot reasonably be attributed to mind-reading from any living person; nor can the result be attributed to mere chance coincidence. It bears all the marks of careful and ingenious design. The most sceptical among the serious students of this kind of utterance have at length become convinced that the explanation of communication from surviving personalities is the only one they can think of which meets the case and that covers all the facts,—whatever outstanding difficulties still surround that tremendous hypothesis. It is not one to be lightly granted or prematurely published broadcast. There should be no forcing of conviction. "Ears to hear" are still necessary.

More Elementary Methods

In studying these messages, it is the phenomenon of psychic control which has to be explained. There is no difficulty about the physical performance itself. The problem is as to the nature and identity of the controlling or communicating intelligence.

Sometimes the hand, instead of writing, is used to point to a set of letters of the alphabet exposed to view, or occasionally,

though rarely, *not* exposed, but screened from the view of the operator; some form of pointer being usually employed as indicator of the letters, for convenience. This is a more elementary form of manifestation; for the letters are already formed, and only have to be pointed at instead of written. Sometimes the muscular action takes the form of tilts or taps, which repeat themselves as the alphabet is recited by somebody present, and which stop when the intended letter is reached. Or else, as in some cases, a tilt is given only when the intended letter is reached. All these variations are trivial: the important thing is the substance of the communication, and the proof of identity which can thus be obtained.

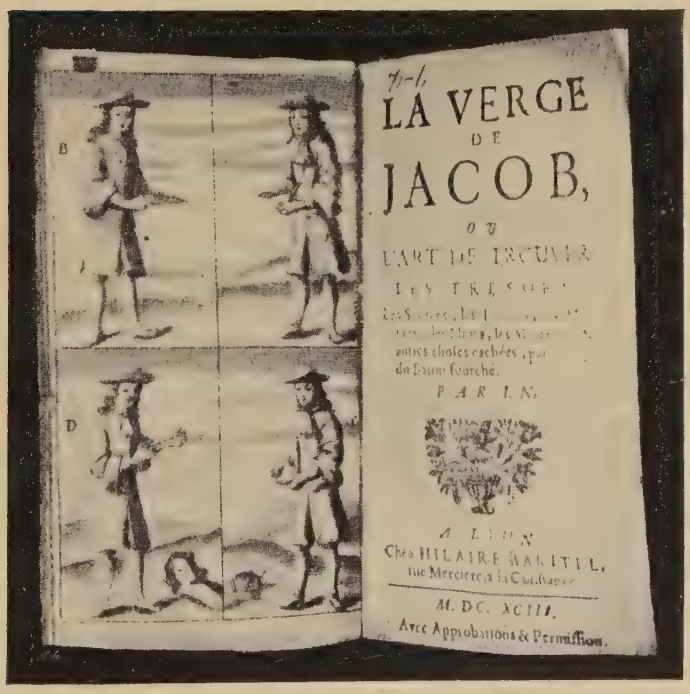
Here, therefore, a caution—a much needed caution. The ease with which communication of some kind can be got, by tilts and by pointing to letters, enables people with extraordinarily small mediumistic power to get results of some kind. So also can they be got, by a fair number of people, through automatic writing. And in many cases it has to be pointed out, politely but emphatically, that what they get is very rubbishy, and may be due to the unconscious tapping of their own dream stratum.

Occasionally, if people are truly susceptible to telepathic influences, even the dream stratum may be the recipient of genuine impressions from a distant mind or scene; and in that case even dreams, as well as the more mechanical methods of tapping the subconsciousness, may be *veridical* or truth-telling,—that is to say, may give information unknown to the persons operating, which yet can subsequently be verified.

This undoubtedly happens occasionally, however it be accounted for; but, as a rule, it may be said that the more mysterious or occult modes of writing, or spelling, or talking, are of no particular value merely because they are puzzling and occult. In some painful cases they are no better than if the person operating allowed the fancy to roam at large and say whatever came into its ken. The tricks of the subconsciousness are innumerable: much more so than novices suspect.

THE EARLIEST KNOWN ILLUSTRATION OF THE USE OF THE DIVINING ROD, APPLIED TO THE FINDING OF PRECIOUS METALS. (From G. Agricola's treatise on Mining, published in 1557.)

At the top a man is seen cutting the rod from the tree; at the left the "Dowser" is seen prospecting with the rod; beneath are two onlookers pointing to the find of metals, and two miners examining the metal dug out.



AN ILLUSTRATION FROM AN OLD FRENCH BOOK ON "JACOB'S ROD," published at Paris in the year 1693.

The four figures show: (*a*) holding the rod and prospecting; (*b*) the man has just found water, which is springing up from the ground; (*c*) has discovered a hidden treasure; (*d*) discovering a dead body by aid of the rod.

ILLUSTRATION FROM AN OLD FRENCH WORK PUBLISHED IN THE YEAR 1693, SHOWING VARIOUS WAYS OF HOLDING THE DIVINING ROD.

§ 8

Summary

The main thing which psychic science has so far established is the possible disconnection of mind and body, the proof that mind can exist, and can even act in certain ways, apart from the usual instrument. This fact has a close bearing on the possibility of survival, for it shows that the mind and personality and character and memory need not become extinct when the brain and other usual organs of manifestation are destroyed.

Mind cannot function, or display itself, without a physiological organ of some kind, but it has shown itself capable of *existing* under other conditions; and, moreover, it can telepathically produce an effect, not only on other minds in like condition with itself, which presumably is easy, but occasionally even on incarnate minds; minds presumably of sympathetic persons who are not too busy to attend, and who are not too wholly and closely guarded by their bodily screen.

For it would seem that the brain and body, being instruments for use during our practical sojourn on the earth amid material surroundings, are adapted to isolate us as individuals and to sever us from a multitude of cosmic influences which would otherwise distract us and prevent our attending to the business in hand. These instruments are not an essential part of ourselves, and we go on without them, but meanwhile they are useful, and in most people give complete isolation for the development of an individual personality,—since the only channels of communication with others are through the physiological sense and motor organs with which we are all familiar. So familiar with the usual methods of communication do we become that we are tempted to think them the only conceivable way. But it turns out that in the case of a few persons—not so few perhaps as had been thought—the screening apparatus is incomplete, the brain is as it were leaky, and impressions can get through from the psychic universe which are not brought by the sense organs and nervous network

to a brain centre, but arrive in the mind by some more direct route.

Such persons are the mediums; and their faculty exhibits itself most readily when ordinary disturbances, and the lights and sounds of every day, are shut off, and when they enter into the quiet.

Something of the same sort has been known to the saints of all time, and also to men of genius. The conditions for meditation, or for high and fruitful production, are similar. But whereas, in the case of lofty minds, things of value are received into the consciousness, and are skilfully worked upon and converted into great discoveries, or immortal poems or pictures, the lowly class of more nearly ordinary people called mediums are as a rule not particularly able or highly educated folk—though there are exceptions—and are only privileged to get inspiration into their subconsciousness in a temporary and easily forgotten manner. They have to let the inspiration, such as it is, be utilised by others, who take the trouble to obey the conditions and to make and study the record of what is given, through their subconscious utterance. Such utterance, whether by speech or by writing, often takes the form of ecstatic description of occurrences and conditions "on the other side," and on the joys and occupations of future existence. Many books recording this kind of information have been published, both in America and England. But, though they may be considered edifying, statements of this kind are not verifiable, and therefore are not yet attended to by psychic science; though, in the case of Swedenborg, they have been made a foundation for religion.

The utterances in which science at present is most interested are concerned with more mundane affairs; they may not seem at all important or edifying to superficial observation, and are often said to be trivial and unworthy of the dignity of the subject—whatever that may mean. One gets tired of pointing out that the triviality of these personal and domestic tests adds to their value

as evidence of personal survival—which appears to be their object. If the events referred to were historical, or even domestically important, they would be recorded in *papers* of some kind, and clairvoyant reading of the record could be appealed to as an alternative explanation, even if a much more commonplace suspicion were not entertained. To complain of triviality in the events selected as evidence for continued personal existence and memory, is stupid, or at least thoughtless. For if, when studied, the best messages are found to constitute links in the chain of evidence demonstrating continued existence or human survival beyond the adventure of bodily death; if they show that we are not alone in an alien universe for some seventy odd years, and are then extinguished as if we had not been, but that an immortal future—an infinite destiny—lies before each one of us; if they tend to prove that the loves and powers and hopes and aspirations of earth persist, that our acts for better for worse are laid to our charge, and that without any sudden change our character goes on developing;—if any weak and halting utterances are able to convey such knowledge as this, no one has the right to stigmatise them as common or unclean.

OLIVER LODGE.

SHORT BIBLIOGRAPHY

Books on the subject are innumerable. The following is a selection:

MYERS, *Human Personality and its Survival of Bodily Death.* (The most comprehensive work on the subject.)

LODGE, *Survival of Man.* (A more popular survey, from personal experience, with special treatment of telepathy and trance phenomena.)

BARRETT, *Psychical Research* (Home Univ. Library). (He has also written on Water Divining and other supernormal faculties.)

HILL, J. A., *Psychical Investigations.* (Mostly about non-trance clairvoyance evidential of survival.)

HILL, *Spiritualism, its History, Phenomena, and Doctrine.* (Gives accounts of the work of the older mediums.)

HOLMES, J. H., *Is Death the End?*

Barrett, *On the Threshold of the Unseen.* (Is a recent book by one of the Founders of the S.P.R.)

As specimens of writings purporting to give higher teachings and some idea of conditions on the other side, the following may be mentioned:

After Death, by W. T. Stead.
Spirit Teachings, by M. A. Oxon.
Speaking across the Border Line, by F. Heslop.
Claude's Books, by Mrs. Kelway Bamber.

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XVII

NATURAL HISTORY

NATURAL HISTORY

IV. BOTANY

WONDERS OF PLANT LIFE

THE genealogical tree of living creatures may be thought of as like a letter V. On the one side are animals; on the other side are plants; at the base there are simple forms of life which have not taken any decisive step in either direction. It is easy to distinguish a buttercup from a butterfly, but it is not so clear at first sight how a mushroom differs from a sponge; and at the base of the genealogical tree there are "Protists," which are sometimes claimed by the botanist and sometimes by the zoologist. Some of these very simple organisms give us a glimpse of what the first living creatures may have been like.

Dependence of Animals on Plants

The image of the letter V is useful, because it suggests that plants and animals, though both alive, are on very different tacks of evolution. But we could improve on the symbol if we showed a tracery of fine twigs, binding the two sides together; for plants and animals have grown up together through the ages and are linked together in mutual influence and dependence. This is the subject of a separate article on INTER-RELATIONS.

There are three great ways in which the animal world as a whole is dependent on plants. First, there is nutritive dependence, for it is wholly through the agency of green plants that animate nature continues as a going concern. Many an animal

devours another, but in the long run animals depend on plants. We see a new meaning in the saying "all flesh is grass." Secondly, there is the fundamentally important fact that the oxygen of the air, necessary to keep the fire of life burning, is produced by green plants, which are able to split up carbon dioxide. In the original atmosphere of the earth there was little or no free oxygen. Thirdly, when we think of one of the greatest steps in evolution, the colonising of the dry land by animals, we recognise that plants prepared the way. Not only did green plants supply food and oxygen; they afforded shelter, concealment, and abundant opportunities for animal adventures. That animals have paid their debts is plain when we think of the making of good soil by earthworms, or the pollination of flowers by their insect visitors.

Importance of Minute Plants

In some way, still imperfectly understood, green plants are able to feed at a very low chemical level, on carbonic acid gas, water, and salts. The energy of the sunlight, shining through a screen of green pigment (chlorophyll), is utilised to dislocate the carbon dioxide molecule, and to begin the upbuilding of carbon compounds, such as sugar. This is the most important process in the world, and is known as photosynthesis—the upbuilding of carbon compounds with the help of the energy of the sunlight. On this depends all the potential energy in the sacks of wheat, in the bales of cotton, in the fields of rice, and in the bodies of animals. The energy of the coal consists of the bottled sunshine of distant millennia.

It is important to form a vivid picture of the circulation of matter in which green plants play so essential a part. The atoms of Carbon, Hydrogen, Oxygen, and Nitrogen are continually changing partners in the never-ceasing dance, except when they sink into a resting group. The carbon dioxide formed in the vital combustion of the animal's body and liberated in the breath may be recaptured by the green leaf. The nitrogenous waste of

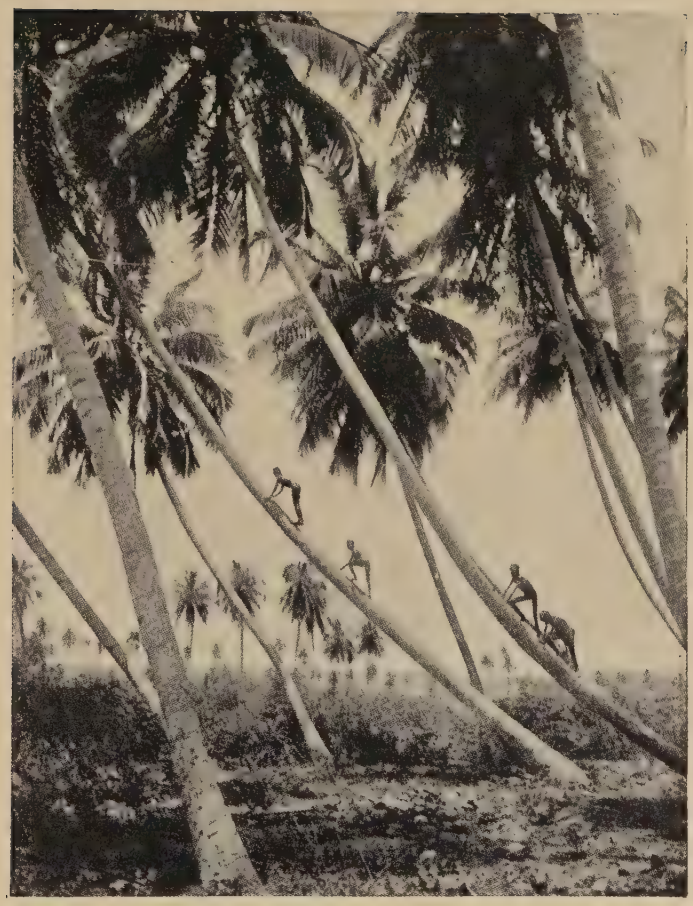


Photo: Underwood & Underwood.

COCO-NUT PALMS NEAR AQUADILLA (PORTO RICO)

The curious inclination of the trees is probably the effect of storms. This palm is one of the most important food plants of the Tropics, and furnishes material for making many other necessities of life. Its products are important articles of commerce. It is probably native in tropical South America, and has been spread far and wide by primitive man.

Photo: F. R. Hinkins & Son.

SECTION OF AN OAK-TREE

Wood formed in spring is light and open in texture; wood formed in summer is dark and close-grained. From the edge of one dark zone to the edge of the next is an annual ring which marks one year's growth. By means of these rings it has been possible to ascertain the age of some red-wood trees to be over 2,000 years. The thickness and structure of the ring give clues to the climatic conditions which obtained when it was formed.

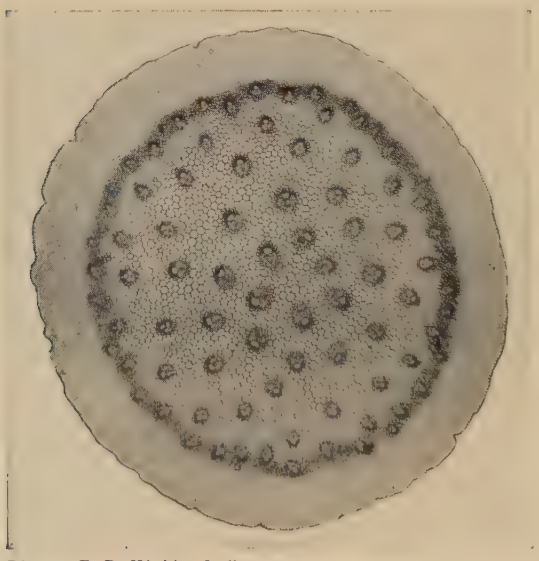


Photo: F. R. Hinkins & Son.

CROSS SECTION OF THE STEM OF THE BUTCHER'S BROOM

The dark circles are the bundles of conducting tubes which provide for the passage of water and food-stuffs through the plant, the clear spot near the edge of each bundle being the largest water-conducting wood-vessel. Between the bundles can be seen the large cells which make up the ground tissue; while to the outside a darker ring marks the position of a band of strengthening fibres.

myriads of birds formed the nitrate beds of Chili, and the nitrogen atoms of these salts scattered on the wheat fields appear again in another grouping in the gluten of bread. The animal dies and sinks to the earth; its body is buried by sexton-beetles; the bacteria which cause all putrefaction break down the tissues into simple chemicals, which plants once more reincarnate in the cycle of life.

In the article on Bacteria it will be shown that these microbes have their finger in many a pie. They are the smallest plants, but their rôle in the economy of nature is of incalculable importance. If green plants be called the "producers," and animals the "consumers," bacteria are the "middlemen."

But we must also recognise the significance of the microscopic green plants of the sea and the freshwaters. Diatoms enclosed in exquisitely sculptured shells of flint (see illustration opposite page 318), and the hardly less beautiful Desmids, swarm in inconceivable numbers in the surface waters, along with other simple Algæ (and some microscopic green animals as well); and they constitute the fundamental food-supply of higher forms of life. All of them are absorbing air, water, and salts; all of them are splitting up carbon dioxide, liberating oxygen, and building up carbon compounds: they make higher life possible. The microscopic specks are not less important than the great seaweeds. If "all flesh is grass," then "all fish is diatom and sea-dust." In the springtime the surface waters of the lake are sometimes green and almost soup-like in the density of their Alga population, and the silent crowded turbulence is spoken of as "the breaking of the meres." A bucket of water lifted from the open sea may contain minute plants far more numerous than the stars we can count on a clear night.

Variety of Plant Life

There is a long gamut from the diatoms—specks of living matter, in beautiful shells of flint—to the daisy, from the hyssop

on the wall to the cedar of Lebanon, from the annuals in our garden to the Big Trees of California which have sometimes lived for over two thousand years. The first plants were probably free-swimming open-sea single-celled Algæ, and there are many of them to-day. As shallow waters were established around up-bulging continental masses, fixed seaweeds began to flourish—fixed to the floor of the sea and yet not out of the reach of the light. At a very low tide it is worth while wading out cautiously among the great seaweeds, some of them many yards long. This is the forest primeval, and it is possible, as Church maintains, that some of them were slowly transformed into terrestrial plants as the shore continued to rise.

On a path of their own are the Fungi—moulds and toad-stools of many kinds—living on rottenness, or as parasites on green plants. Among them, but rather by themselves, most botanists include bacteria. Lichens are strange double plants, consisting of Algæ and Fungi living together in intimate mutually beneficial partnership. On a higher level are the sprawling liver-worts, and above them come the mossses, the ferns, the horsetails, and the club-mosses. The beginning of Seed Plants may be traced very far back, probably to the Devonian period, but it was not till the geological "middle ages" that they began to come to their own. It was a great step in evolution when seeds were established, for that meant—as in mammals among animals—that what was liberated from the parent was a young plant which had lived for a considerable time in the seed-box, as it were in partnership with its parent. Conifers and Cycads represent a lower level than the ordinary flowering plants like grasses and lilies, daffodils and orchids, buttercups and poppies, roses and lupins, bluebells and daisies. The variety suggested by these names seems endless, but the flowering plants fall into well-defined groups, and it is possible to work out a pedigree tracing them back to a few common ancestors. Just as all the important varieties of cultivated wheat can be traced back to the Wild Wheat, which still grows on Mount

Hermon, so a genealogical tree can be constructed for the orders of flowering plants, and for the vegetable kingdom as a whole.

Common Characters of Plants

Amid many idiosyncrasies, and in spite of some great exceptions, such as moulds and mushrooms exhibit, there are some important common characters which bind plants together. There is the general possession of the leaf-green pigment called chlorophyll, conspicuous by its absence in the fungi and in the strange dodder, a flowering plant which victimises others. Then there is the fact that the unit-masses of living matter that build up the plant are boxed in by walls of cellulose—a carbohydrate with the same formula as starch ($C_6 H_{10} O_5$). This imprisoning of the living matter within very definite cell-walls—which do not occur among animals—implies a great restriction in the motor activities of the plant, and determines in great measure the lines of their everyday activity. Another feature of plants is the absence of any method of gettting rid of the nitrogenous waste-products. All living involves the breaking down of proteins, with the consequent formation of nitrogenous waste. This waste is got rid of in higher animals by the kidneys and the skin. But in the plant the deposition, instead of the elimination, of nitrogenous waste must tend to depress vital activity and deepen its slumbers. For a plant is rarely more than half-awake.

As has been already indicated, it is characteristic of plants to be able to feed at a low chemical level and to be able to effect photosynthesis. But this must be added, that typical plants, as compared with typical animals, are predominantly constructive, accumulating energy progressively, gathering stores in large quantity, often, it would seem, beyond what they can possibly need. Their particular regime or metabolism leads to a great hoarding of reserve products, to which vegetarian animals do justice in their explosive, adventurous life; and it must be remembered that as plants cannot move about, except in the case

of some of the simplest, they depend for their racial survival on vegetative increase, on endowing their offspring with large legacies, and on being able to lie low within retrenchments abundantly provided with stores.

The Essential Parts of a Flowering Plant

The poet Goethe was one of the first to see clearly that an ordinary flowering plant consists essentially of two parts—the axis and the appendages. The axis includes (1) the upward-striving stem, which seeks the light and grows against gravity, and (2) the downward-boring root, which avoids the light and grows towards the centre of the earth. The appendages are the leaves which the stem spreads out to the light and in the air; and the flower consists typically of four tiers, or whorls, of transformed leaves—the sepals, petals, stamens, and carpels—the two last producing reproductive cells. It is interesting to examine in the spring the opening buds on the horse-chestnut tree, for they show so clearly every grade between the scales that protect the bud and the ordinary leaves with their five leaflets. And a little later we may profitably examine the beautiful flower of the white water-lily to see the transitions between the green sepals and the white petals, and the transitions between the petals and the pollen-producing stamens. When a wild flower like a briar rose goes "double" in a garden, this means that a large number of transformed leaf-structures, which should have become stamens, have gone back into sterile petals. We see, then, that the general architecture of a plant is very simple compared with that of most animals.

§ 1

The Laboratory of the Green Leaf

It is now necessary to consider in more detail how plants feed. Plants receive their raw material by means of their leaves and by their roots. The green leaves of plants receive carbonic acid gas

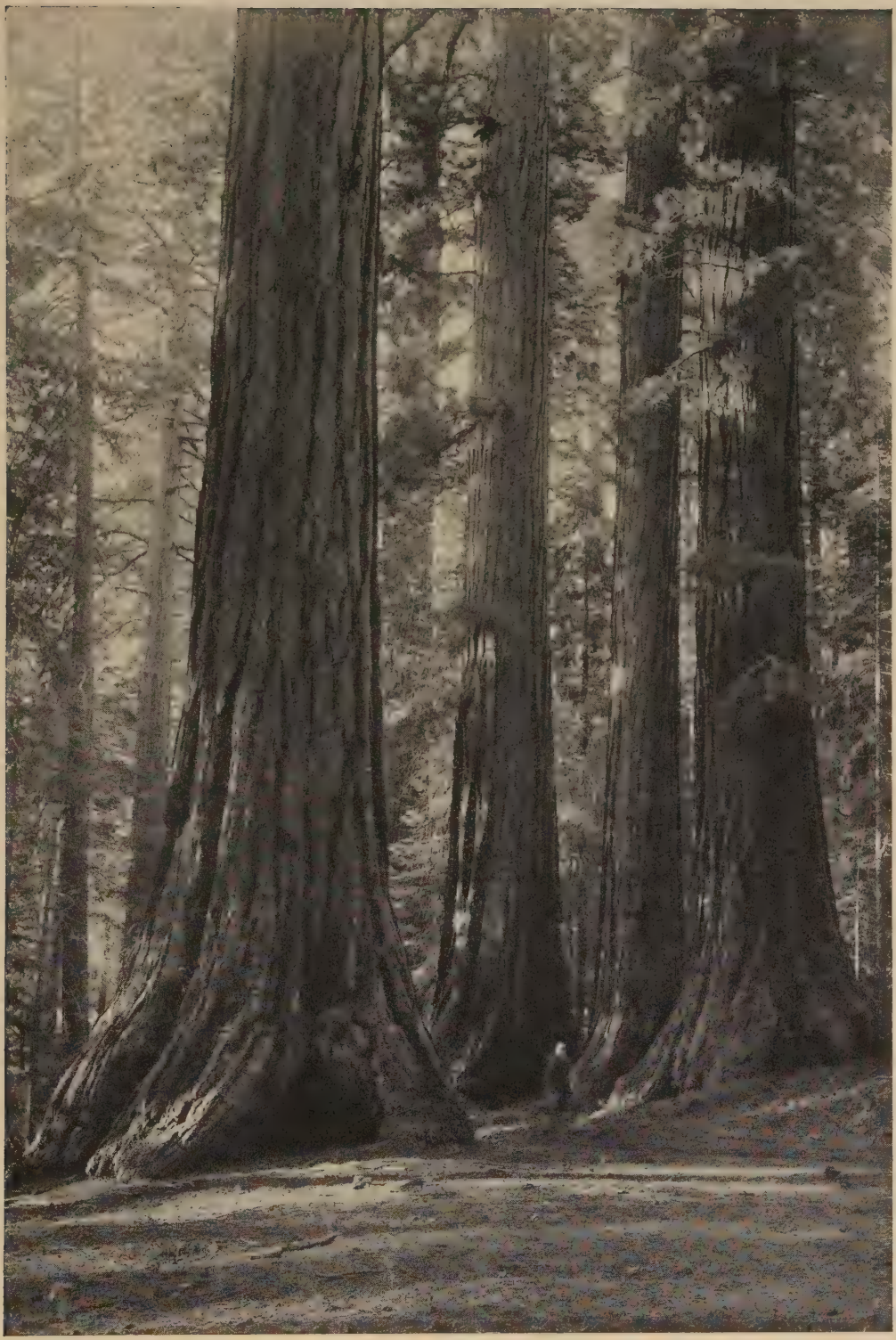


Photo: H. J. Shepstone.

THE BIG TREES OF CALIFORNIA (*Sequoia gigantea*)

Some are over 300 ft. high, and are rivalled only by the Blue Gums of Australia. They have had a longer life than any other living creature. Prof. Dudley says: "Of the various trunks examined, ranging from 900 years upwards, the oldest possessed 2,425 rings, or had begun its existence 525 years before the Christian era." They are able to "heal" or cover over great wounds, such as those made by fire. What the tree does is to extend or fold its living tissue over the wound, and the process may take scores of years.

Photo: Underwood & Underwood.

Victoria regia, THE GIANT WATER-LILY OF THE AMAZON

Those shown are in a public park in Minnesota and are able to support the weight of a child. In their native home the leaves are said to be ten feet in diameter.

from the air. The raw material they take in by means of their roots is no less indispensable, and this consists of water and mineral salts from the soil. Water enters the roots from the soil solution, drawn in through the thin-walled and delicate root hairs which arise near the root tip and are continually renewed as the root grows. With this stream of water the plant receives its supply of mineral salts. From the air there passes into the leaves a slow current of carbonic acid gas. This is present in the atmosphere in the small proportion of three parts in ten thousand; and the loss due to constant absorption by the plant is made good by the respiration of animals and the burning of fires.

What the Green Plant Does

The raw materials with which the plant works are thus water and mineral salts from the soil and carbon dioxide from the air. The green leaf is the laboratory in which the chemical syntheses take place.

What goes on in this laboratory? Mainly the manufacture of such chemical substances as starches, sugars, and oils, which are essential to living beings. The bulk of living substance is composed of four ubiquitous elements—carbon, hydrogen, nitrogen, and oxygen—besides other elements such as phosphorus and sulphur. Nitrogen compounds are supplied in solution by the root of the plant, carbonic acid gas is drawn from the air by the leaves. The plant breaks down the various compounds under the influence of sunlight, and builds up the chemical elements into fresh forms, whose great peculiarity is that they possess potential energy. All life depends on the peculiar green substance "chlorophyll." It is only the plant that manufactures this essential chlorophyll. Animals take all their organic compounds ready-made from plants, and rebuild them into their own living matter, and use them as a source of chemical energy. The plant *manufactures* these organic compounds. The making of the leaf-green pigment called chlorophyll is in most plants carried through with

the co-operation of sunlight. All plants, as we have said, absorb air, water, and salts; all of them split up carbon dioxide (carbonic acid gas), liberating the oxygen, which goes off free once more into the air, and building up the carbon compounds which make all higher life possible. Thus we see that we owe to the plant the oxygen of the air necessary for life. In an aquarium which has no artificial aeration, the animals will die if there are not enough green plants to keep up the supply of oxygen in the water, and the same is true over the earth as a whole. It is plants alone that can make organic matter (energy-yielding material) direct from dead or inorganic material. Every living animal in breathing gives out carbonic acid gas, and it is this gas which makes badly ventilated rooms stuffy when there are large fires and many people breathing. Yet it is food for the plant! The laboratory of the green leaf, then, manufactures an energy-yielding product. In the leaf-cell the chlorophyll acts as an energy transformer and absorber. As energy cannot be created any more than it can be destroyed, what is the source of this energy which the plant makes available?

If we burn a piece of cotton wool, which consists almost wholly of the carbohydrate called cellulose, its carbon combines with oxygen from the air, and the combustion results in carbon dioxide, water vapour, and a fluff of mineral ash. But besides these *materials* there are also liberated two forms of *energy,* namely heat and light. This energy was locked up in the cellulose, and it follows that if the plant has built cellulose from the raw materials carbon dioxide and water, it must have got possession of some energy corresponding to that which escapes as heat and light during burning. The source of this energy is sunlight.

The Capture of Sunlight

A green leaf is a few cell-layers thick, and is traversed by veins, the transport system by which water enters the leaf and elaborated food is carried away. Their branching network pro-

vides for the effective distribution of water to all the living cells. The lower skin of the leaf is pierced by minute openings—the stomata—so numerous that there may be one hundred thousand to the square inch. Through these minute openings water vapour flows out, and carbon dioxide flows in. They communicate with a system of air spaces in the leaf which allows a supply of the gas to reach every cell. The leaf-cell is the actual laboratory in which the upbuilding of food takes place; it includes, embedded in the living matter, numerous biscuit-shaped green bodies (chlorophyll corpuscles), whose function it is to absorb and transform the light energy.

The flatness of the leaf means a large absorbing surface, and the arrangement of leaves is suited to avoid mutual shading, and consequent loss of light. The leaves of ivy on a wall look like a mosaic, small leaves fitting into the space left by the larger ones. The branches of trees are scaffoldings which spread the foliage to the light, and all the devices of twining, climbing, and rambling plants serve the same end—namely, the capture of parts of the sunlight.

To the leaf-cell, then, there flows water with salts through the veins, and carbon dioxide through the stomata and air spaces. In the cell there is an energy transformer and absorber, the chlorophyll. In the cell, too, there is protoplasm, the physical basis of life, which utilises the raw materials and the energy of light, so as to transform the carbon dioxide and water into simple organic compounds of carbohydrate nature. In this process there is a liberation of oxygen, which passes out by the little openings. The formation of these simple carbohydrates is the fundamental process of plant nutrition, and indeed of life in general on our globe, for from them are derived all other organic compounds whatever, in animal as well as in plant.

It will be noted that this process of *photosynthesis* is the exact reverse of the vital combustion which all living implies, where organic substance is combined with oxygen, breaks down into

carbon dioxide and water, and gives up its store of energy. This continued production of carbon dioxide would, if there were no counter-process, lead to a cumulative vitiation of the atmosphere. It was the attempt to find the counter-process that led to the discovery of the plant's mode of nutrition. The discovery was made by the English chemist and philosopher, Joseph Priestley, one of the founders of modern chemistry.

What Food is Used for

The sugars and the like that green plants make in their leaf-laboratory may be used in the leaf itself, or first transported to some other part. The plant moves but little, and then slowly; its temperature is scarcely raised above that of the surrounding air; and so it requires only a fraction of the energy used up by the animal, in moving and heat production. What energy it does expend is chiefly employed in carrying out chemical transformations and in the processes of growth. This energy is obtained, as in the animal, by oxidation or combustion processes, and an appreciable quantity of carbohydrate is used up in this way. Here we may note that in plants the using up of oxygen and the giving off of carbon dioxide, which may be briefly called respiration, is demonstrable only in the dark. It undoubtedly goes on all the time, but as long as the plant is illuminated the respiratory process is completely masked by the much more active counter-process of photosynthesis which we have discussed. Carbohydrates are also transported from the leaves to other parts of the plant to be restored as reserves, often after conversion into other forms. The commonest food reserve is starch. This storage of food is a characteristic feature of plant life, and it is wrapped up with the habit of evading adverse conditions, such as cold in temperate climates or drought in arid regions, by passing into an inactive resting state. The resting parts, such as bulbs or tubers or seeds, usually contain a good store of food, and at the expense of this the plant can make a flying start when conditions are once

Photo: J. J. Ward.

HORSE-CHESTNUT (*Æsculus hippocastanum*)

The arrangement of leaves is such that good illumination is secured. This horse-chestnut shows a mosaic pattern, the smaller leaves filling up spaces between the larger; over-shadowing is thus reduced to a minimum.

Photo: James's Press Agency.

DODDER (*Cuscuta epithymum*)

This flowering parasite may be seen on the furze and ling of the Surrey heaths. The thread-like stems twine round the host plant; they put out small suckers which drive their way through the rind and take what nourishment is required. They bear no leaves, but only the clusters of bell-shaped flowers.

Photo: J. J. Ward.

ROOTS OF THE WILD WHITE CLOVER, SLIGHTLY ENLARGED, SHOWING THE LITTLE ROOT TUBERCLES

These are swellings which harbour a particular race of bacteria with the power of fixing atmospheric nitrogen. The clover plant benefits by obtaining a supply of nitrogenous compounds, and the soil is enriched on the death of the roots and the rotting of the tubercles. Plants of the clover family have an important effect on soil fertility.

more favourable. On the thrift of the plant in this respect the human race depends.

Finally, the carbohydrates, in the leaf or after transport elsewhere, are used to form other substances, such as cellulose, oil, chlorophyll, and living matter. In intricate ways the salts from the soil help in the transformations.

§ 2

Nutrition of the Fungi

There are, however, some plants which possess no chlorophyll, and are in consequence unable to build up for themselves organic food from inorganic materials. Most familiar are the multitudinous fungi, which have probably been evolved from various groups of algæ, and include such diverse types as the skin of blue mould on jam, the fur of black mould on bread, the fawn-coloured mushroom of the meadows, the bright-hued toadstools of the woods, the rust disease of wheat, the mildew of gooseberries, the blight of potatoes. All these and innumerable others are dependent on the organic food formed by some other plant. One group called saprophytes feeds on decaying organic matter, another group called parasites subsists on living hosts. The toadstool and the mushroom grow in the soil like any green plant, but in situations where the soil is rich in organic matter; the toadstool lives in the leaf-mould of the wood, the mushroom in the well-dunged pasture. The food-supplies of the fungus mould on bread or jam, or of the mildew on the gooseberry, are obviously generous. From such sources the fungus draws its nourishment ready made.

Saprophytic fungi may play an important part in aiding bacteria to break down dead organic matter into inorganic compounds, which may be used once more by green plants. Some are of direct economic importance on account of the by-products of their vital processes; thus the yeast plant is a fungus which forms alcohol from sugar.

But those fungi, the parasites, which feed on the living plant, are often very harmful, sapping the substance of their hosts and killing them by the poisons they manufacture. They are the chief causes of plant disease, and we get a glimpse of their fatality when we see a potato field reduced by blight, in a week or two, to a mass of rotting and offensive haulms.

Lichens as Double Plants

The familiar lichens, which cover such unpromising places as stones and tree-trunks, are *double plants,* composed of a fungus and an alga growing together in a partnership so intimate that the result maintains a specific form. Without the aid of the microscope their dual nature would never have been discovered, and it was not held definitely proved until the two partners had been separated by a delicate technique, grown in isolation, and then made to reconstitute the lichen on being brought together once more.

Flowering Parasites and Saprophytes

Among the flowering plants there are some very interesting saprophytes and parasites. Thus, among British plants the bird's nest, the bird's-nest orchis, and the coral-root are saprophytes, the first belonging to the heath family, the other two being orchids. All three grow habitually in the leaf-mould of woods, a soil rich in decaying organic matter. Though the details of the relationship are not fully known, it seems that a symbiotic fungus which inhabits the roots of these plants play some part in making the food in the soil available. In none of the three is there any chlorophyll; the bird's-nest is cream-coloured, the two others are dirty brown. Even the leaves are much reduced, being represented only by pointed scales.

More familiar are parasites, such as the mistletoe, the dodder, and the broomrapes. The mistletoe is only partially dependent on its host, the apple or the fir, for it has green leaves, and can manufacture carbohydrates for itself.

The Story of the Whin

Green plants, too, may be constantly associated with partners belonging to lower groups. If we dig up a young whin or broom and examine the roots we find that they bear a profusion of warts, ranging from the size of a pin-head on the smaller rootlets to lumps the size of a pea on the larger. These are abnormal swellings of the root tissue caused by the presence of a particular race of bacteria. The bacteria enter the root hairs from the soil, and, multiplying, travel inwards till they reach the rind-cells of the root. There they increase and pass from cell to cell as the root tissues enlarge in response to the irritation of the invaders. A mature wart or nodule cut across and examined with the microscope shows the cells packed with myriads of bacteria, and it has been proved that these are able to fix the nitrogen of the atmosphere—always present in solution in the water which enters the plant—and to convert it into organic compounds. Part of the supply is at the service of the host, and in return the bacteria are supplied with carbohydrate food. This extraordinary association is another example of symbiosis—a mutually beneficial internal partnership.

These bacterial nodules are found on the roots of all members of the great family of the Leguminosæ, the pod plants, to which belong broom, whin, lupin, pea, bean, vetch, rest-harrow, and many others familiar as wild flowers or important as food plants. The members of the Leguminous family number some eleven thousand and are to be found over the whole globe. But their success may be appreciated by anyone who has travelled only as far as the nearest common, or even a little way along the road leading to it. For the heath and the common are clad with whin, and the road is flanked with broom, shrubs the luxuriance of which in stature, blossom, and seed is at strange variance with the unpromising conditions of soil on which they flourish. It is the possession of a private store of nitrogen compounds, supplied by the bacteria, which makes this success possible.

Root-Fungi

The roots of many other plants, such as the beech, the pine, and the heaths, are associated with symbiotic fungi (Mycorhiza), and in some cases there is evidence that the fungus supplies its host with nitrogenous compounds. The best-authenticated case is that of the heaths. These plants inhabit barren moorland stations. In such situations relatively few species of plants are able to flourish, and the vegetation is usually dominated by a few which are specially endowed—on the common by the whin, on the moor by the heather. The whin has its root-bacteria; the heather has a fungus which spreads all through it and enables it to utilise the peaty soil. Thus the heather is in large measure an impostor; it thrives because it is interpenetrated by a partner fungus.

§ 3

Insectivorous Plants

On wet moors there grow three genera of plants which show yet another method of supplementing the food supplies obtainable from the soil. These are the sundews, the butterworts, and the bladderworts, several species of each of which occur in Britain. These plants catch small flies and crustaceans, and absorb the products of their decay, or even actively digest them. They all possess chlorophyll, and it is in the supply of proteins, and possibly of salts, which the victims offer, that we find the explanation of so curious a habit.

The rosy leaf of the sundew is covered with little club-shaped tentacles, short-stalked at the centre, long-stalked round the margin. On the thickened end of each is a drop of sticky fluid, which, glistening in the sun, gives the plant its name, and which serves to catch "incautious, deluded insects." The entangled midge struggles, comes in contact with more tentacles, and is held more firmly. Stimulated by contact with the solid body, stimulated too by the chemical action of the insect, the marginal tentacles of the plant, even though they are not touched, soon begin

Photo: James's Press Agency.

THE COMMON SUNDEW (*Drosera rotundifolia*)

The leaf has many club-shaped hairs or tentacles, the heads of which are extremely sensitive to touch. They secrete glistening sticky fluid, and there may be two hundred on a single leaf. Particles of sand, wood or glass will produce no secretion of the glands, but a caught insect or a small piece of meat will do so (see next illustration).

Photo: J. J. Ward.

HOW THE SUNDEW CAPTURES INSECTS

Another illustration of the sundew's tentacles. It is the drops of sticky fluid on their ends which serve to attract insects. An unfortunate insect alighting on one causes the tentacles to bend over and pin down the struggling victim, in this case an ant. Digestion follows, and after a few days, when the tentacles bend back again, only a shrivelled husk is left.

Photos: S. Leonard Bastin.

VENUS FLY-TRAP (*Dionæa muscipula*)

The first photograph shows the bristle-like hairs of the fly-trap open. When the insect touches the bristles, the two halves of the leaves clap together in something less than a second and the insect is captured, as shown in the second photograph (see also colour plate for illustration of the Venus fly-trap plant).

Reproduced by permission from the "Scientific American."

MINIATURE JAPANESE TREES OF THE CHABO VARIETY, WITH THEIR ROOTS EXPOSED

These triumphs of the art of the Japanese gardener are obtained by sowing small seed in small pots of poor soil, growing the seedling in the least favourable conditions, and otherwise maltreating it. Conifers can be obtained which at an age of a hundred years are only a foot or so high.

Photo: J. J. Ward.

ROOTS OF BEECH-TREE

A widespread and complicated branching system is necessary alike to absorb sufficient water for a forest tree and to support its crown. The roots remain near the surface, scarcely reaching a depth of three feet.

to fold inwards. The stimulus spreads, and the struggling midge is pinned down in the centre of the leaf. Secretion of fluid increases, and in it the insect is first drowned and then digested. Some days after the fatality the tentacles bend back once more, uncovering a shrivelled husk. The leaf is ready for fresh prey.

The butterwort, like the sundew, traps its prey by a viscid secretion; it possesses no tentacles, but the margins of the boat-shaped leaves, covered with tiny glands which secrete the sticky matter, roll inwards. Digestion is slower than with the sundew, but ultimately the softer parts of the insect are absorbed and only the husk is left. The bladderwort adopts other means. It grows submerged in pools of peaty water, and, as is the case in many water-plants, its leaves are divided into fine threads. Some of these are replaced by bladders about one-tenth of an inch long. The bladder opens in front by an arrangement like the door of an old-fashioned mouse-trap. Small freshwater crustaceans get entangled in a tuft of hairs projecting over the door, and force their way in. The door of the trap falls to behind them and cannot be opened from the inside; they swim round and round till they die, and then under the action of the bacteria of decay their bodies rot and are absorbed.

Pitcher Plants

Curious as are the British carnivorous plants we have just described, they are excelled, alike in numbers and in refinement, by those of the Tropics. Visitors to the glass houses of the Botanic Gardens at Kew or Edinburgh are familiar with the pitcher plants, Nepenthes and Sarracenia. Most of the Nepenthes are natives of the Malay region, where they ramble and climb through the bush. They have large leathery leaves prolonged into whiplike tendrils. The end of the tendril, after it has grasped its support, develops into the pitcher, which in some species is as large as a quart pot, in others as small as a thimble. Over the mouth arches a lid which prevents the entrance of rain, for the liquid with

which the pitcher is partly filled is a secretion of the glandular cells of the wall. The inner surface of the rim is set with nectar glands, and below these the wall is made very slippery by a coating of wax. So it comes about that an insect, attracted by the nectar and straying on to this glissade, slips into the fluid and is drowned. During the subsequent slow digestion the body is not attacked by bacteria, for the fluid in the pitcher is antiseptic as well as digestive and so keeps the food fresh.

Venus Fly-trap

Most wonderful of all is the Venus fly-trap, a relative of the sundew, growing like it on bogmoss, but found only in the Carolinas. Its leaves are over an inch long, each with a winged stalk and a rounded blade. On the upper surface of each half of the blade are three prominent bristles; round the margin is a row of stiff processes. If an insect touches one of the bristles the two halves of the leaves clap together in something less than a second, the marginal processes interlock like the teeth of a rat-trap, and the insect is captured. And then there are many suggestive details, such as Sir John Burdon Sanderson's discovery, that the closing movement of the leaf is accompanied by an electrical change similar to that associated with the contraction of one of our muscles. Then follows a secretion so abundant that the fluid oozes out from the edges of the trap. Digestion and absorption follow in due course. After a while the leaf reverts to its normal state of expectancy.

§ 4

How Plants and Animals Agree

If we trace an oak-tree back to a sapling, and thence to a seedling, and thence to a seed and an ovule, we come at last to a fertilised egg-cell, which is the beginning of the individual life. In this respect the oak-tree agrees with the squirrel on its branches. Moreover, in both cases the fertilised egg-cell divides

and re-divides, forming thousands of cells, a mode of development which allows of considerable division of labour. But we can go a step further and say that plants and animals agree not only in the individual beginning and in their cellular structure, but in the essential processes of life. Both show nutrition and the distribution of the food through the body; both show digestive ferments and breathing. It is true that photosynthesis is peculiar to green plants, and that there is little in the vegetable kingdom corresponding to the kidney function in animals; yet there is much in common among all forms of life.

It may appear at first sight that this conclusion breaks down badly in regard to moving and feeling, which are the master-activities in the animal and are anything but conspicuous in most plants. Yet when we begin to think of leaves rising and falling, of flowers opening and closing with the waxing and waning light of day, we see that there is much movement. And when we begin to think of the way stems bend to the light and roots make for moisture, or of the sundew answering back to the fly's touch, of the tendril responding to its contact with a slender twig, we see that there is much feeling in plants. In the Far East the Sensitive Plant often grows in great masses, and if a stone be sent crashing in among them one can see the leaves sinking down into the collapsed rest position, and the stimulus spreading in a circle like a splash in a pond. The Venus fly-trap may be cheated by a little piece of moist paper and made to close on booty not worth having, but if it be cheated twice in rapid succession it will not usually answer back to a third duping. This is surely the beginning of memory—an enregistering of experience so that future activity is modified. We need not consider in detail the modes of movement among plants, but just as many a sedentary animal like a coral or a sea-squirt shows something of the plant in its somnolent constitution, so we may say that the animal is lurking in many a plant. There is more than a trace of a dream-smile in many an orchid.

It is always useful to recognise similarity in the midst of difference, but it is a mistake to exaggerate this so as to obscure significant divergence. It is of the very nature of plants to be sluggish. It is bound up with their independent mode of nutrition. They do not need to seek out their raw materials; they need only absorb the constantly renewed supplies of water and salts brought to the roots by the slow draining in the soil, and of carbon dioxide flowing over the leaves in the currents of the air. While the animal, essentially a hunter, has advanced to an ever-increasing perfection of co-ordinated movement, the plant has sunk into torpor. There are exceptions among the lower groups; many primitive algæ swim actively, the sponge and the sea-anemone are sedentary; but the true contrast between the two kingdoms is seen in the squirrel romping through the boughs of the impassive beech. The distinction between active animal and sluggish plant is fundamental.

The Tactics of Plants

Plants live their lives much as animals live theirs: every plant is adapted to its particular station in life, and in its adaptations we see the outcome of the same struggle for existence and the same fundamental vital qualities (growing, multiplying, answering back, and so on) as we see in animals. There is the same competition, the same mutual aid where mutual aid pays. The plant, like the animal, shows the same self-preservative instincts; the same factors of environment and heredity determine the individual life. There are new departures—new novelties among pansies, as we see among pigeons. Plants multiply; on the whole they may be said to inherit the character of their parents; the same continuity of linkages as in animals binds one generation to another. In the plant world as in the animal world Nature cares more for the race than for the individual. Thus we get in a general way the impression of plants as genuinely living creatures.

Plants, like animals, employ their own peculiar tactics in

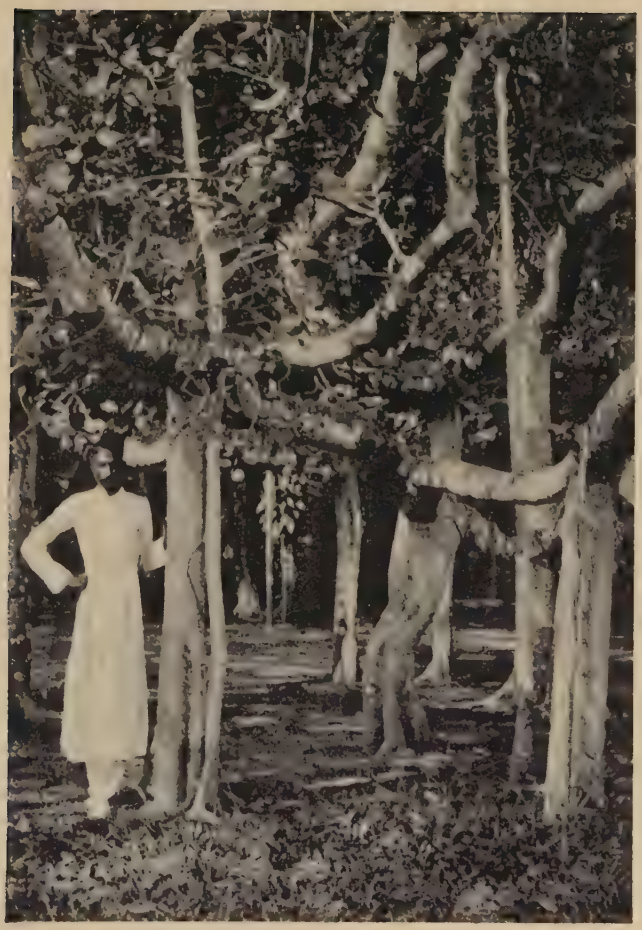


Photo: Underwood & Underwood.

A BANYAN-TREE (*Ficus benghalensis*)

One single banyan-tree, 1,000 feet in circumference, at Calcutta. The branches send down roots and these grow into massive stem-like pillars. What appears to be a grove is a single immense tree.

Photo: J. J. Ward.

THE THORNS OF THE ROSE AND OF THE BRAMBLE (RIGHT) SERVE A DOUBLE PURPOSE

They are sufficiently barbarous to protect the plants from browsing animals. Especially in the bramble, they also help to secure the trailing stems, preventing them slipping from the supports over which they ramble.

Photo: J. J. Ward.

FLOWERS OF BARBERRY

The stamens of a number of flowers move in response to the touch of a visiting insect. In the barberry the stamens lie back in the boat-shaped petals. A touch on the filament or stalk causes the stamen to move inwards sharply towards the ovary. Here they are holding a large pin with which they were touched. An insect doing this is dusted with pollen.

adapting themselves to environment; we may suppose that an act of the plant is just as full of practical import as that of an animal: in the latter case the act may suggest intelligent behaviour, in the other it is only the result of an inherited tropism. The plant, like the animal, can camouflage and deceive. The pitcher-plant and bladderwort are as guilty of false pretences as the spider; the sundew and the fly-catcher are adepts in preparing a bait for confiding insects. The white ant will squirt an obnoxious juice in the face of an attacker; so do plants produce poisonous and evil-smelling substances to keep off an enemy. Each species lives for itself; no species ever undertakes anything for the sake of any other, except in the expectation of a corresponding advantage. If the wild thyme lays by in its throat abundant honey for the bee, that is because the bee carries its pollen from blossom to blossom.

§ 5

The Part the Root Plays

Typically the main root grows straight down, the main stem straight up. If a seed happens to be planted right way up the young root and stem grow on in the way they are pointing; but if the seed lies on its side or is inverted, the root and stem make active curvatures till they point in the proper directions. When we sow seed we do not require to arrange it also; we leave proper orientation to the powers of the growing plant. Indeed, in many seeds the embryo is originally curved and must in any case straighten out. Nor is this power confined to the seedling stage; a stem which has been bent over curves up, in the growing apical part, in the course of a day or so. The plant is capable of active curvature, and this movement is set agoing by some external directive influence.

> The movements of roots, as they grow in the earth, suggest that they are seeking for nutriment. Spots in the earth which are found to be unfavourable to progression are

> avoided with care. If the root sustains injury, a stimulus is immediately transmitted to the growing part, and the root bends away from the quarter where the wound was inflicted. When the exploring root-tip comes near a spot where water occurs with food-salts in solution, it at once turns in that direction, and when it reaches the place develops such absorptive cells as are adapted to the circumstances.[1]

We have seen what part the roots play, in drawing nourishment from the soil for the plant. The part of the growing root most sensitive to stimuli is the tip, and the phenomena which are exhibited in consequence of its great sensitiveness are so astounding that Darwin compared the root-tip to the brain of one of the lower animals. He wrote:

> It is hardly an exaggeration to say that the tip of the radicle thus endowed, and having the power of directing the movements of the adjoining parts, acts like the brain of one of the lower animals; the brain being seated within the anterior end of the body, receiving impressions from the sense-organs, and directing the several movements.

But modern botanists describe the same facts in less picturesque language—in terms of engrained "tropisms."

The roots penetrate and explore and feel their way underground, touching here, recoiling there, and insinuating themselves in such a way that they search every part of the soil. The length of roots is sometimes very great. The root-system of a large cucumber plant was estimated by Mr. S. Clark in all its ramifications at 25,000 yards (fourteen miles), but this is open to doubt.

> Clover roots are said to go down to depths of six or nine feet, but many weeds go deeper still. Coltsfoot, for instance, may be found, living at a depth of twenty spades. In Egypt and other places the roots of acacias go down to twenty feet, or

[1] Kerner.

even farther, so that they can tap the water supplies, which are at a great depth.

The root-system of a tree only one year old may have a total length of 12 yards.

Darwin showed that a root from which about one-twentieth of an inch of the tip has been removed does not respond to gravity if laid on its side; it grows straight on. But if a root is first laid on its side for a few minutes and then decapitated, it does, after a few hours, curve downwards. He drew the conclusion that, while the reaction takes place in the zone of most active growth about one-fifth of an inch behind the tip, the effect of gravity is registered by the extreme tip only. Later ingenious experiments have confirmed this result.

Plant Tropisms

There is a close correspondence between plant-responses and the tropisms exhibited by animals (see p. 78), and the plant's answer-back to gravity is called geotropism. But while the moth which flies into the candle flame perceives the stimulus of light by special sense organs, the eyes, and moves by special motor organs, the contractile muscles, and has these linked by special conducting organs, the nerves, the root has at its disposal no such complex and highly specialised structures. Perception and conduction take place in the general living matter; reaction is due to a slight change in the growth rates of upper and lower sides. Darwin's comparison of the root-tip to a brain is really far-fetched.

Ingenious attempts have been made to show that the plant has sensory organs of a primitive kind, for the perception of gravity, light, and touch. In a group of cells within the root-tip there are numerous large starch grains which lie heaped up on the bottom wall. If the root is laid on its side the starch grains fall over and come to lie on the side wall, which is now lowermost. It

is suggested that the root is in equilibrium only when these starch grains rest on the true bottom wall; that if they lie on a side wall the difference is perceived, and the root curves till the tip points downwards, the grains resume their proper position, and equilibrium is restored. It is certain that some Crustaceans maintain their balance by a similar apparatus of grains of sand resting in the cavity of the ear. In the case of the root the experimental investigation is beset with difficulties. But though the theory cannot be regarded as definitely established it possesses considerable probability, and it may be that in these special cells we have the nearest approach that the plant shows to a sense organ.

Why does the root curve down and the stem shoot up? To that question we can as yet give no answer. We can only say that it is their nature so to do. Many botanists expect, however, that as our knowledge of the varying structure and composition of living matter grows more precise, we shall be able to interpret the matter in terms of physics and chemistry; the theories which have been formed so far are unsubstantiated—the imagination of the scientist occasionally outruns his facts.

§ 6

Tendrils

The stem of the plant supports the leaves in the light, but in many plants a weak stem bears the weight of the leaves by twining round some stronger neighbour. The twining movement is of immense importance to plants like our honeysuckle, hop, and bindweed, which are thus much superior to the bramble, rambling over a stone wall secured only by its spines, or the goose-grass, rambling over the bramble secured only by its hooks. In the great forests of the Tropics a great proportion of the vegetation consists of such types—the lianes—twining round trees, twining round each other, forming an impenetrable confusion of coiled and twisted cordage, reaching out to the light above the forest roof, supported on the dead pillars of trees they have strangled.

Photo: J. J. Ward.

THE WEB OF A SPIDER

A typical web consists of (*a*) strong foundation lines round the margin, (*b*) the rays radiating out from the centre, and (*c*) the concentric rings or the continuous spiral of viscid silk on which the insects are caught. In order to construct the rings or the spiral, the spider first makes a primary spiral binding the rays together and forming a scaffolding. This is afterwards removed. The spider is often not on its web, but in an adjacent shelter, and a special line running from the web to the den makes the spider aware of visitors. The nature of the vibrations may also indicate whether the visitor is unwelcome, like a wasp, or welcome, like a fly. The spider's web is an intricate system subtly bound together, and it might serve as a sort of symbol of the web

Robert Louis Stevenson gives a graphic picture of this form of the struggle for existence in his poem of "The Woodman." The twining movement, like the movement of the root-tip, is regulated by gravity.

Tendril-bearers respond to another influence, that of contact with a solid body. Like the tip of the hop, the whip-like tendril of the bryony sweeps round in a circle. This movement is not directed by external stimulus, but is purely automatic. But if the tendril touches a twig, a wire, a leaf, or another tendril, it is stimulated by the contact to more rapid growth on the side *away* from the exciting object, and so curves *towards* it. As it goes on curving, fresh portions come into contact, and are stimulated, so that the whole tip becomes tightly wrapped round the support. Later the basal part twists into a corkscrew spring once or twice reversed, and then becomes thick and woody. This spring breaks the force of the tug of a passing animal or of a gust of wind, and saves the plant from being torn from its support. In his *Climbing Plants* Darwin describes the conspicuous success of the bryony in riding the storm which battered many other plants.

The tendrilled plant is more highly adapted for climbing than the twiner. The latter loses a third of its length in its coils, and while it can use only such supports as are nearly vertical, the tendril encircles anything that is solid and not too thick. The tendril represents some part of the plant turned to a new use. In the sweet-pea it takes the place of the apical leaflets, in some vetchlings it replaces the entire leaf, in some tropical orchids it is a root, in the bryony and in the vines it is a branch.

If we gently stroke the under side of the bryony tendril we can readily observe the answer-back; after a few minutes the tendril curves towards the side touched. Only a solid body can induce the response; a stream of water, a violent rain shower, even rubbing with a stick of semi-solid gelatine, has no effect. Here is a fine example of delicate adjustment, for response to rain-drops would be of no use to the plant, would even deprive it of oppor-

tunities of clasping proper supports. The tendril responds only to the touch that helps it. It is to the same stimulus that the sundew tentacles react when they fold on a struggling fly, though the movement is intensified by the insect's chemical action.

Light and other Influences

The seedling, fresh from the protection of the seed-coats, young and delicate, is at once affected by all the influences of the world into which it has come. Gravity is not the only directive agency. The root grows against some shard, is slightly wounded, and turns away from the source of injury. It rubs gently against grains of soil, and the contact causes it to move gently to and fro; it feels its way through the crevices of the soil. It comes to a dry region and bends to the moister side. But the shoot, subject to all these stimuli in the soil, finds yet another director in light when it reaches the air.

Everyone knows the window plant, with the shoots bent to the light, the leaves twisted round and spread flat to catch the rays. Light interferes with the action of gravity on the stem, and is the primary cause of leaf movements. Its action is complicated by the fact that, unlike gravity, it is constantly changing its intensity and direction. Few plants can react so quickly as to follow the sun; moreover, as growth ceases, the power of movement ceases, except in the case of those leaves which have jointed stalks. So it comes about that most leaves, as they mature, adopt a fixed position in relation to light.

§ 7

Sensitive Plants

The Sensitive Plant is a vigorous shrub, usually reaching a height of some feet in our hot-houses. Each graceful leaf has a stalk jointed to the stem, from the tip of which spring four secondary stalks, each with a double row of leaflets; the foliage stands out from the stem, the leaflets are expanded. If the plant

is gently shaken, instantly the leaf-stalks droop, the secondary stalks fall together, the leaflets fold up; the whole scaffolding of green light screens has collapsed. In nature, a wandering animal or a shower of rain brings about the same result, a series of movements so rapid that the reaction is complete in a few seconds. Soon a reverse sets in, and a quarter of an hour later the plant is in its normal condition again.

A violent shock is not necessary; touch the lower half of the joint of the leaf-stalk and it droops; a little later the secondary stalks come together, then the leaflets fold up in succeeding pairs. Singe the apical leaflet and the chain of reactions is reversed. Make a cut in the stem, and first the nearest leaf reacts, then the next, then one further away. The shock-stimulus is passed on. It is conducted at the rate of an inch in the second; this is a thousand times slower than the conduction along an animal's nerve, but a hundred times as quick as the rate commonly developed in plants. The movement itself is slow compared with the wink of an eyelid, but very fast in comparison with that of an inverted root bending downwards.

The movement is different from that of a curving root or stem. It depends on a sudden diminution of pressure in the cells of the lower half of the joint, which thus loses its rigidity and collapses. This allows of a very rapid fall; it also allows of the occurrence of the movement long after growth has ceased.

Of what use to the plant is this spectacular reaction? It has been suggested that the rapid closing shakes off small insects feeding on the leaves. It has been suggested that the plant thus avoids damage by violent rain or hail. It has been suggested that browsing animals are frightened by the sudden change in the appearance of their pasture and repelled by the thorny appearance of the closed plant. It cannot be said that these explanations are convincing. They do not apply at all to a dozen other plants which show similar but less active leaf movements. The only animal that shows a distaste for the Sensitive

Plant is the goat, which is not a native of the plant's original home in South America. We know, too, that repeated movement is actually harmful. A plant which had been stimulated twelve times daily for three weeks attained to only one-third of the height of another left undisturbed. It was handicapped in assimilating power, but probably, in addition, the constant irritation upset its constitution in some profound way. Is it better to take the chance of being eaten or the certainty of being stunted?

The reaction to shock brings with it clear advantages in other cases. The leaf of the Venus fly-trap folds quickly together on the slightest touch of one of its sensitive hairs. In nature the touch is that of an injudicious insect which is subsequently crushed, drowned, and digested. The little filaments or stalks of the stamens of the cornflowers contract instantly by 30 per cent. when touched. The result is that the anthers, from which the pollen has been shed, are pulled down over the brush of the stigma, and the pollen is swept out and exposed to visiting insects which carry it to other flowers. The bilobed stigma of the musk closes on the pollen. In this case, and in others like it, the movement has an obvious biological advantage.

Do Plants Sleep?

As night falls, the trefoil leaves of the clover fold their leaflets up, the daisy flower closes, the tulip becomes once more a bud, the leaflets of the wood-sorrel droop and close: the plants sleep. The term sleep, consecrated by long usage, is not a happy one, for with the sleep of animals this movement has nothing to do. It brings no recovery from a non-existent fatigue. It is in reality an active movement, not a collapse. Only in the seeming relaxation recurring as darkness comes on is there a superficial resemblance to the real relaxation of the animal and to the drooping of its drowsy lids.

The tulip flower, like that of the crocus, closes as the air

Photo: Underwood & Underwood.

CULTIVATED BAMBOO IN A CHINESE PLANTATION

These giant grasses are sometimes 120 feet high and one foot in diameter. They grow at times at the rate of three feet per day. The bamboo is one of the most important Asiatic economic plants, being used in building houses and in making furniture, implements, utensils, ornaments, and paper. The young shoots are eaten like asparagus.

Photos: J. J. Ward. 1. 2.

THE "SENSITIVE PLANT" (*Mimosa pudica*)

1. When one leaf-tip is touched or injured all the little leaflets fold up one after the other, then the secondary stalks drop, and the main stalk of the leaf droops downwards. Soon the next leaf acts in exactly the same way. The closing of the leaves may be produced by a severe shaking or by holding a lighted match below the leaf-tip. The illustration shows the expanded position of the leaves in the daytime.

2. Showing the leaves in closed or night position. A shower of rain will cause the leaflets to fold up in a few seconds. The photographs show a seedling plant.

Photos: J. J. Ward.

BRANCH OF WILD CAMOMILE (*Matricaria chamomilla*)

The left-hand photograph was taken at midday and shows the flower-heads flat; the right-hand photograph was taken at 6 p.m., and shows the flowers reflexed. Most flowers close to a bud at night, but the camomile folds its petals further back. The advantage of this is not clear, and it may be merely an exaggeration of the normal movement of the expanding flower, but there may be some purpose served.

cools and reopens in the sun's warmth. By alternately raising and lowering the temperature it may be made to open and close several times in one day. The daisy and the marigold open in the light and close in the dark; the night stock opens in the dark and closes in the light. The marigold, too, may be made to open and close as many as three times in the twenty-four hours; it may be made to open at night and close through the day by suitable changes in illumination. But its case is not so simple as that of the tulip, for, when kept in continuous dark, it opens and closes day and night. Even a flower which has opened for the first time in the dark, and has been kept thereafter in continuous dark, which has never experienced the daily change, carries out the periodic movement regularly.

In the case of leaves the movement is induced by the change from light to dark. But in leaves, too, it may take place in continuous light or continuous dark. A scarlet runner may be raised from the seed in darkness and an even temperature, and under these conditions the leaves rise and fall day and night.

In such cases there is evidently a periodic movement independent of external changes in illumination and temperature, though these changes certainly strengthen and emphasise the normal daily swing. In some cases the periodic movement may be due to an after-effect of the induced movement. But in the scarlet runner raised from seed, in the marigold brought to flower in continuous dark, this cannot be so. It is likely that the effective influence is some change in the electrical condition of the atmosphere; but the possibility of an inherited periodicity must be considered.

The significance of these sleep movements is still a matter of discussion. Darwin tried to show that they benefited the plant by saving it from excessive radiation and cooling on clear cold nights. Other investigators see a use in the avoidance of the deposit of dew. Flowers may save their pollen from being spoiled by rain by closing in dull weather.

§ 8

How Plants Protect themselves

Even this short survey shows that the power of limited movement in plants is widespread. The tropisms are specially important, for with their aid the plant arranges its organs so as to make the best of its environment. The ultimate position of leaf, stem, and root is the result of balanced reactions to all the influences that play on the plant throughout its growth. But the power of movement is nearly always restricted and gentle, confined to arranging the members of a stationary organism. Active locomotion belongs to the animal kingdom. Perhaps the nearest approach is in the telegraph plant (*Desmodium gyrans*) from the plains of the Ganges, in which there are continuous movements of the leaflets in little orbits; but no one knows why this plant should be so busy.

We have said that plants live their lives very much as animals live theirs; like animals they have to protect themselves against natural enemies.

Many animals live exclusively on a vegetable diet; as there are plants that strongly object to being eaten, they take effective measures to protect themselves; if they did not, the herbivorous animal itself would suffer, for its means of subsistence would in time disappear from the face of the earth. One means of defence employed by the plant is poisons and corrosive fluids, which it uses to good effect. But sometimes what is one animal's food is another's poison. For instance, the leaves of the deadly nightshade form the most important food of a small beetle, but the foliage is poison to the larger grazing animals.

It is not clear to us how grazing animals discriminate between what is harmful to them and what is not harmful. Many plants have characteristic odours offensive to us. Others are odourless to the olfactory nerves of man, but they may make themselves known to the animal's sense of smell. Wild animals probably recognise the dangerous plant by colour, smell, or taste.

The leaves of nettles, etc., have stinging hairs or bristles as protection against the attacks of large herbivorous animals. The stinging hair plays an important part, as it penetrates the skin and injects into the wound a poison which causes the painful "burning" sensation.

In the cactus-like plants the variety of weapons is considerable. A single species often bears three or four kinds of weapons. They are armed with large spines and small bristles, short, thick and thin, knotty and smooth, straight-pointed and barbed. And so by thorns, spines, and prickles, plants often protect themselves.

The nectar of some flowers intoxicates the bees, who are believed to acquire a taste for it. In his *Botany of To-day,* Professor Scott Elliott describes a well-known orchid which has a hinged lip:

> When the unsuspecting insect enters the flower and passes over the lip, it is suddenly jerked forward and thrown into a sort of bath of liquid; as it painfully crawls out, with wetted wings, it has to carry away the pollen masses, and so effect pollination. There is no cruelty in this, for the insect is supposed to visit another flower and cannot be much harmed.

§ 9

HOW PLANTS ARE REPRODUCED

In that great burst of activity in spring which heralds the approach of warmer weather, plants make an irresistible appeal to the eye. We welcome the clear colours of the snowdrop, celandine, and violet, and still more the bursting bud and shooting blade covering the earth with a hundred delicate shades of green. The tree unfolds its leaves, and root-stock and bulb push up new shoots through the soil; such plants wake from their annual rest and embark again on an active period. Among them arise myriads of seedlings, new plants growing from germinating seeds; in these

we see a complete new start, the production of new individuals, the result of reproductive processes completed months before, in the previous summer and autumn. (See the article on the Biology of the Seasons.)

The Meaning of the Flower

The seed—the kernel in the nut, the pip in the apple—comes from the fruit, and the fruit is the end of the flower. So it is the flower that is concerned with the reproduction of the higher plants.

What is a flower? If we examine a buttercup or a lesser celandine, we find to the outside a number—five or more—of green scales, the sepals (together forming the calyx), which in the bud protect the delicate internal parts, and afterwards steady the full-blown flowers. Then comes the corolla of bright yellow petals. Inside the corolla are numerous stamens, each with a stalk or filament bearing a head, the anther, which contains the pollen. In the centre are many small green grains, the carpels, in each of which is an ovule or possible seed, containing an egg-cell.

The shape, colour, number, and arrangement of these parts vary greatly from flower to flower, and on the floral characters the classification of the flowering plants is largely based. In many flowers some of the parts are wanting or are greatly altered in appearance. In the tulip the calyx, like the corolla, is brightly coloured, and the carpels, three in number, are united to form an ovary containing many ovules. This union of the carpels occurs too in the poppy, foxglove, and many others. In the grasses the calyx and corolla are absent, or represented by minute scales; the work of protection is taken over by small green leaves which correspond to the three leaves which stand out below the flower of the anemone. In the hazel there are flowers with stamens only, gathered in golden drooping catkins, and flowers with an ovary only, grouped in buds, each crowned with a tuft of

Photo: J. J. Ward.

WOOD-SORREL (*Oxalis*)

The leaves are seen in "sleep" position. They fold up at night, and seem to withstand cold better. They also fold in very bright sunlight, and thus avoid overheating. Apart from these conspicuous movements the leaflets continually move slightly in an irregular fashion. They also close if shaken violently.

Photo: J. J. Ward.

A CACTUS (MAMMILLARIA)

The Cactuses are inhabitants of the arid regions of America. The thorns are modified hairs and effectively protect the plant from animals.

Photo: James's Press Agency.

LADY'S-SLIPPER ORCHIS (*Cypripedium insigne*)

The lip of the flower forms the "slipper." Insects such as bees wander inside this and can only get out in one particular way, in which they must touch first the stigma and then the stamens, thus carrying out cross-pollination. Flowers have endless contrivances by which the insect is forced to do work of this kind.

Photo: J. J. Ward.

THE BUTTERFLY ORCHIS (*Oncidium papilio*)

The orchids show the utmost refinement of floral structure. This West Indian flower resembles a butterfly, and like the British Bee Orchis, which resembles a bee, it seems to frighten away insect visitors. The result is that pollination often fails and the flower sets no seed. The mimicry is here of no apparent use.

crimson filaments. In the willow the two kinds of flower grow on separate bushes.

The Secret of the Seed

Before the ovule can develop into a seed, the egg-cell it contains must be fertilised by the pollen. The pollen is received on the stigma, a moist receptive surface, sometimes borne on a long style, as in the sage, sometimes sessile on the ovary, as in the tulip. The pollen-grain germinates and sends a fine tube down through the tissues of the style and ovary to the ovule. The process of fertilisation is preceded by a long process of intricate preparation. In the ovule there has been formed a single large cell—the embryo-sac—containing a number of cells, of which two are important; of these one is the egg-cell or female reproductive body.

The germinating pollen-grain contains three nuclei, one of which is the male reproductive body or sperm. When the pollen-tube reaches the ovule it brings its contents to the embryo-sac, and the sperm and the egg-cell fuse together. In each of these there is packed away the inheritance of one parent; the result of the fusion, the fertilised egg-cell, contains all the factors which, as development proceeds, will stamp the new organism with the features of its kind. The egg-cell, stimulated by fertilisation, commences to divide and grows into an embryo with a root, two leaves, and a shoot bud; these parts can be easily seen if we open up a soaked pea or bean. Development goes so far and then stops; the young tissues dry up as the seed ripens; it is cast loose in a state of rest. The higher plants, like the highest animals, liberate young ones; they are truly viviparous.

Why Flowers are Bright

In the flower, then, we recognise the ovary as the organ which contains the female reproductive bodies, in which the seed is matured; the stamens produce the fertilising pollen; the calyx

is protective. But we have assigned no function to the corolla, that part which, to our æsthetic sense, is the essence of the flower, giving it distinctive form, giving it colour, frequently giving it scent and sweetness. For the nectar glands are in some flowers associated with the petals, though in others with the stamens or ovary.

The form of the flower, in particular the character of the corolla, is intimately bound up with the pollination, with the means by which the pollen is transferred from the stamens to the stigma.

The flower is now understood as an arrangement by which pollination is secured. Though the four parts of the flower have different names and forms and uses, they have fundamentally a common nature, for they are all leaves, transformed in various ways and combining to fulfil the plant's chief end—that it should produce seeds which will develop into full-grown plants and bear next year's flowers. All the differences in the form and position of the floral parts, which give individuality and character to different flowers, may be referred to the variety of means employed for securing the transference of pollen, which precedes fertilisation. Perhaps nowhere else in nature can we see so clearly the fineness with which two organisms—flowers and their insect visitors—are fitted to each other.

But while on the whole the variety of bright flowers corresponds to the variety of insects that visit them, or to the different ways in which one insect may work, it is not true that insects alone are important in carrying pollen. There are flowers in the Tropics pollinated by humming-birds; a few of our native flowers, for example those of the golden saxifrage, are pollinated by slugs; aquatic plants, the grasswrack of the sea as well as the pondweeds and others of fresh water, have water-borne pollen. These are relatively small classes, but rivalling the insect-pollinated plants in numbers are all those plants with inconspicuous flowers, trees and grasses, which are pollinated by the wind.

If the supply of food gives the insect a material inducement to frequent flowers, colour and fragrance guide the visitor in choosing its particular source of supply. The golden standard of the broom, the glowing purple of the sage, heather, or thyme, the massed yellow flower-heads of sunflower or marigold, the white expanses of hedge-parsley and hawthorn, are illuminated signs advertising the goods within. That insects can distinguish between different colours is still a little doubtful, for it is not easy to discriminate between colour as such and the intensity of light reflection. To our senses colour is the most prominent feature of the flower, but to the insect scent may be more important. We know that insects can perceive odours to us quite imperceptible; it may be that they can discriminate between scents which to our coarser senses are the same.

While colour and scent are the guides, floral structure determines what insects can profitably visit a particular flower, and often decides the manner of the visit. Thus a flower like the hedge-parsley has its nectar freely exposed so that flies and such short-tongued insects can easily reach it; the nectar cup being shallow all may drink, and flies wander about over the inflorescences distributing pollen indiscriminately. But in a flower like the sage the nectar is concealed at the bottom of the deep corolla tube; it can be reached only by long-tongued bees, and the bee must enter the flower in one particular way. The lower lip forms a landing-stage to which it clings; it thrusts head and thorax into the corolla throat, pushing against the lower ends of the two pivoted, lever-like stamens, the upper ends of which swing down and dust the bee's back with pollen at a definite point. On subsequently visiting a somewhat older sage flower the bee first pushes against the forked stigma, which at this stage projects from the hooded upper lip, and so the pollen from one blossom is deposited on the stigma of another of the same kind. In such a flower as the sage, pollination can take place only in a perfectly definite fashion. Thus, small flies cannot work the lever of the

stamens: they are of no use to the plant, and in fact they are prevented from reaching the nectar by a circle of stiff hairs halfway down the corolla tube, a palisade which they cannot penetrate.

Such refinements are especially characteristic of those highly specialised flowers which, like the sage, the orchids, the toad-flax, and the broom, possess bilateral symmetry. This permits of the formation of a landing-stage for heavy insects, and also leads to adaptations which keep the visitor to one path. These adaptations are well fitted to secure cross-pollination, which is advantageous as regards both quantity and quality of seed. Insect-pollinated flowers are not always bright. Thus the cuckoo-pint attracts flies by a carrion stench, perhaps also by the lurid purple of the club of its flowering axis. The flies are trapped among the female flowers by a circle of hairs (modified stamens) inside the base of the hood. They are liberated by the withering of the hairs, when the staminate flowers are ripe; dusted with pollen, they then escape to other plants.

There are fruits, for example, the banana, which ripen without pollination. There are even cases, like the brambles and the hawkweeds, where the sexual process has been so completely dispensed with that *seeds* are formed without fertilisation. But usually pollination is a necessary preliminary to fruit and seed production alike. Sometimes, when a plant is grown in a foreign country, artificial pollination must be resorted to; the marrows and peaches in our gardens and hot-houses are commonly pollinated by hand. The red clover never set seed in New Zealand till the humble-bee, to which it is adapted, was introduced.

Wind Pollination

In wind-pollinated plants the adaptations run on different lines. The pollen is dust-like and is produced in enormous quantities, for the chances of a grain borne in the air reaching the stigma of a flower of its own species are remote. The grains are

Photo: James's Press Agency.

CUCKOO-PINT (*Arum maculatum*)

The flowers are hidden in a large green hood or spathe, in the mouth of which can be seen the club-like end of the floral axis. This club attracts flies by its lurid colour and its fœtid smell. A kind of arrow-root has been obtained from the root, but it is difficult to separate it from the poisonous juice.

Photo: J. J. Ward.

GOAT'S-BEARD (*Tragopogon prasense*)

Two of the seed-like fruits are seen floating in the air sustained by their parachutes of firm stiff hairs. The flowers of this plant close before midday, and it is often called Jack-go-to-bed-at-Noon.

Photo: F. R. Hinkins & Son.

CUCKOO-PINT (*Arum maculatum*)

Part of the sheath has been cut away to show the little flowers inside. The female flowers, at the foot, are mature before the male flowers. Small flies are trapped by the ring of hairs, which are modified stamens. When the fertile stamens have shed their pollen the hairs wither and the flies escape, carrying the pollen to other flowers.

Photo: F. R. Hinkins & Son.

CARLINE THISTLE

The enormous success of the plants of the thistle family is largely due to the effectiveness of their method of seed distribution. The lightest breeze is sufficient to raise thistledown and to carry it over long distances.

small and light; in the pine they are provided with two little bladders, the better to float in the air. Conspicuous corollas are useless; they would even be a hindrance, catching the flying pollen and preventing it reaching the stigma. The corolla has almost entirely disappeared, the wind flower is small and inconspicuous. The stamens hang far out of the flower on slender filaments, dangling in the air, shaken by every gust. The stigmas, too, protrude—the crimson filaments, of the hazel, the feathers of the plantain, the brushes which hang from the grass ear—winnowing the air for drifting pollen.

Cross-pollination is secured by having male and female flowers on separate plants, as in the poplar, or by ripening the stamens and stigmas at different times, as in the grasses and plantains.

Cross-Pollination: its Meaning

Cross-pollination is of great importance to the progress of evolution. By it the various new characters which are always cropping up in different plants of a species are combined and recombined, so that an infinite number of races is produced for the sifting process of natural selection to work on. By cross-breeding, in nature as in the garden, the advance of evolution is speeded up. There are also cases where cross-pollination secures a stronger progeny; the maize is a notable example, and one thinks of Darwin's primroses. But it seems that this is due to a re-arrangement of the hereditary complex, and not to any essential stimulation. There are certainly many plants which get on very well without cross-pollination, and there are many others which are adapted to secure self-pollination if the cross fails.

The abundant well-filled capsules which ripen among the leaves of the sweet violet in autumn are not the product of the spring flowers, so well adapted for insect visits but somehow so seldom visited; they come from flowers hidden among the leaves, little green buds which never open, the stigmas of which receive pollen from the stamens of the same flower.

Significance of the Seed

The seed is generally considered the reproductive body of the flowering plant, but if we consider the process outlined above we see that the true reproductive bodies are the egg-cell and the sperm-cell. When the egg-cell is fertilised by the sperm-cell the initiation of a new individual is complete. All subsequent events are stages in the development of that individual; the seed is merely a phase, at which development has been temporarily arrested.

This arrest, the formation of a seed, has two functions. It provides for a dormant period and it provides for distribution. Delicate leaves and shoots are not fitted to withstand extreme conditions, whether the rigours of the northern winter or the prolonged drought of more arid climates. The resistant leaves of the evergreens persist through the cold months, but broad-leaved trees shed their leaves and present bare branches to the storms; herbaceous plants die down, persisting underground as root-stock, rhizome, and bulb, buried deep from the cold. But the seed is the most striking resting phase in the plant's life-history. Dried up, its vital activities are reduced to a minimum; its close-textured coats protect it; it can resist temperatures far below any occurring in the coldest winter; it can withstand considerable heat; many seeds preserve their life for decades. The seed can carry the plant over the most unfavourable conditions of nature; for many plants it is the only resting and resistant stage.

As important is the function of distributing the individuals of the race. Fixed in the soil as soon as it germinates, the plant can travel only at this specialised stage of its career. So the ripe seed is cast loose from its parent.

§ 10

The Travels of Plants

Plants travel in many ways. As the pod of the broom ripens, the drying tissues contract at different rates, and internal strains

are set up. There comes a point, usually when the sun is hot, when the junction of the valves gives way, and, with a little report, they flick into spirals, jerking the seeds out to a distance of some feet. It is not far, but it is far enough to prevent that immediate overcrowding which would occur if all the harvest of the bush fell straight to earth. Then the seeds may be carried away by ants for the sake of their little orange oil bodies; these travel further, and if they come to be buried, not too deep, in an anthill, their chance of germinating in favourable conditions is rather increased.

Many plants depend on animals for seed distribution. The burr of the goose-grass is a dry fruit covered with hooked spines, which catch in the coat of a passing sheep or rabbit. The water-fowl lifts a little dab of mud as it rises and flies to a fresh marsh. In the mud there may be a dozen seeds. But most conspicuously adapted for animal distribution are the fleshy fruits, attracting by their colour and rewarding by their food-value. The seeds of such fruits—apple, cherry, gooseberry—are protected by very resistant coats, and pass undigested through the animal's food-canal. The germinating seedling benefits from the circumstances of its deposition. The thrush eats the berries of the mistletoe, and wipes the seeds off its bill on to the bough on which it sits. The seeds adhere firmly to the branch as the glutinous juice dries, and in the following spring germinate in the position they require.

Movements of wind and water carry seeds to great distances. Darwin showed that many seeds can float on salt water for weeks or even months and germinate at the end. By ocean currents the vegetation of strand and mangrove swamp has spread through great regions of the Tropics. It is probable, too, that seeds of inland plants washed down rivers, stuck in crevices of sticks, have crossed the seas and colonised new countries.

The wing of the maple fruit, of the pine seed, of the ash, allows the burden it supports to volplane through long distances

as gusts of wind lift and scatter. Still more effective are the tufts of hair which crown the fruits of dandelion and thistle with down, or the seeds of willow, cotton, and willow-herb. A light fruit like that of the groundsel is sustained in the air by the gentlest of currents. It has even been suggested that the eddy caused by the sun's rays striking the white tuft, and warming the atmosphere round it, is sufficient to lift the seed in perfectly calm air.

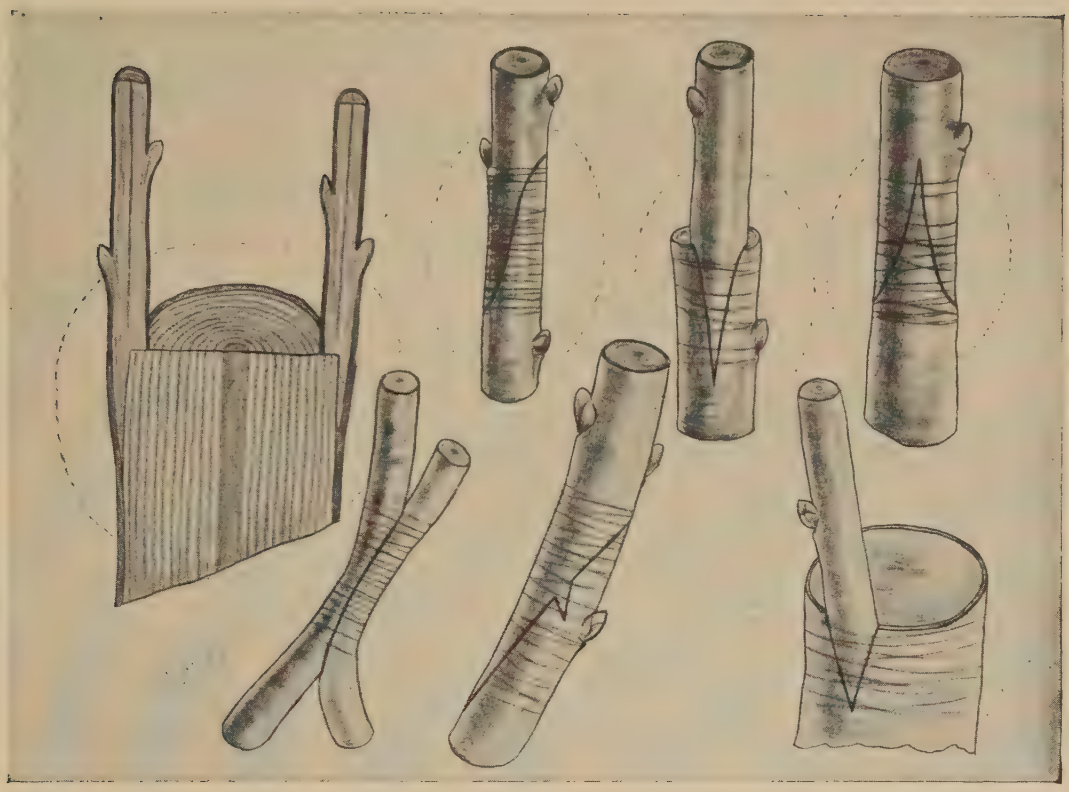
It is not surprising that plants which drift in currents of water and air should be widely distributed. The duckweed, floating in slow streams, carried on the feathers of aquatic birds, is cosmopolitan. The groundsels, an immense genus with over 2,000 species, took their origin in the Bolivian Andes. Evolving new species on their way, they travelled along the great mountain chains till they covered the earth. Beside such wanderings the feats of a Marco Polo, even of a De Rougemont, pale.

Vegetative Multiplication

Gardeners often propagate plants by methods which dispense with seeds. They use slips and cuttings, they graft and bud. The success of the cutting depends on the ready formation of roots from near the cut surface; to go a little deeper, it depends on the loose integration of the plant's organs, on the power of independent existence possessed by separated parts. In the case of grafting there must be added the faculty of uniting with the tissues of the stock. This is not true reproduction; here is no fresh start from a fertilised egg-cell. We may call it vegetative multiplication.

In nature similar processes are of frequent occurrence. The runners of bugle or silverweed take root and grow into new plants, separated in time from the parent by the death of the connecting pieces. Rhizomes of the bracken, anemone, or couch-grass, branch, and the branches become separate plants. Bulbs and tubers, as of the scilla and lesser celandine, bud off young

Crown or Rind grafting. Splice grafting. Cleft grafting. Saddle grafting.



In-arching. Whip grafting. Notch grafting.

Photo: F. R. Hinkins & Son.

METHODS OF GRAFTING

The fact that the growing tissues, or cambiums, of two stems can unite intimately makes it possible to graft one plant on another, if the two are fairly closely related. We are able thus to supply a fine fruit or flower with abundant water and salts from a vigorous stock.

Photo: The Fleet Agency.

TREE SURGERY

Modern tree surgeons prolonging the life of valuable trees by chiselling out the decayed part. After treatment with disinfectant and water, the cavity is filled with a concrete preparation. This is possible because the bulk of the central wood is not necessary for carrying water and may be removed if the tree is mechanically strong enough. The removal of the decayed part prevents infection spreading.

plants. Water plants branch vigorously, and the branches, torn apart, start life on their own. The water thyme, introduced from America to two or three places in England in the forties, is now spread over the whole country; at various places and times it has been a serious menace to navigation. This enormous multiplication has been entirely vegetative. The male and female flowers are formed on different plants, and only the female was brought to England. In its eighty years' colonisation it has never set seed.

Such plants seem to have entirely dispensed with the process of sexual reproduction. Whether they can go on indefinitely or whether, for continued vigour, sexual union must take place now and again, we do not know. It is remarkable that so important a food plant as the banana has been multiplied vegetatively for hundreds or even thousands of years.

Reproduction of Lower Plants

In the lower plants the reproductive processes are very different from those of the flowering plants. The cone-bearers —yew, pine, fir, cedar, juniper—produce seeds which are not enclosed in a fruit; the ovules are exposed on the surface of the cone scales. Even the "berry" of the yew is merely a fleshy outgrowth only partly covering the seed.

A degree lower we come, among existing plants, to the ferns and their allies, the club-mosses and horsetails, and these bear no seed.

On the back of the frond of a fern are to be seen little clusters of spore-cases, each of which contains numerous spores. A spore is a reproductive body consisting of a single cell. When it germinates it grows, not into a fern plant, but into a green blade or prothallus a quarter of an inch long. On the lower side of this prothallus are formed sexual reproductive organs, producing egg-cells and sperms. The sperm is provided with cilia, and lashes itself through the films of surface moisture to

the egg-cell, which it fertilises. The fertilised egg-cell develops into a new fern plant. A single cycle of the life-history of the fern is divided into two phases, a sexual prothallus and an asexual spore-bearing fern plant. There are two alternating generations. The mosses, a side branch of the evolutionary tree, show the same features. The moss plant is the sexual generation; the capsule, parasitic on its parent, is the spore-bearer. The resting distributing body is, in both mosses and ferns, the spore.

§ 11

The main line of evolution was that which led through the fern-like plants to the flowering plants. There was evolved a vegetative equipment suitable to life in moist soil and dry air; absorbing root-hairs, roots, water-conducting tissues; light-absorbing leaves, borne aloft on a branching stem. The method of reproduction was gradually transformed till, in the flowering plant, a stage has been reached where the original equipment is barely recognisable. The plant is definitely emancipated from the medium in which it took its origin; fertilisation is now preceded by pollination, and in providing for that the plant has evolved, in relation to the insect, the flowers we know to-day.

The Fall of the Leaf

Some plants are annuals and some perennials. Once annuals have flowered and the seed has been set, they wither and die. Perennials live on for several seasons. In these, and in shrubs and trees, reserve food stores of starch and oil are available in spring for forming the new foliage. Lilies and onions store reserve material, accumulated during the summer, in their bulbs. Other plants store material in underground tubers, which may be modified stems or roots. We may fitly close our study of the living plant by picturing the fall of the leaf, which so often marks the end of the year's activity. We have taken the follow-

ing passage from Professor J. Arthur Thomson's *Natural History Studies*:

> The life of the plant is like a tide; it sets in with a flood in the spring, manifesting itself in growth of stem and exuberance of foliage; it rises to the high-water mark, and turns in summer when the blossoms burst and the flowers shine forth; it is well on the ebb by autumn, bearing on its breast all manner of ripe fruits and seeds, treasures to be cast on the shores of another spring. Each of these tidal periods, one may say, has its characteristic colour: green and gold are the colours of early spring; orange, red, and purple mark the full splendour of summer flowers; the autumn, with its flame-like, often blood-like, withering leaves, rivals all that has gone before. Is it not true to say that the ebb-tide gleams with the glare of burning wrecks?
>
> Throughout the summer the leaf has lived an intense life, far more intense than we are inclined to give plants credit for, building up with the aid of the sunlight no small quantity of sugar and more complex carbon compounds, which are laid up in reserve in various parts of the plant. In autumn, however, the vitality is checked; the movements of the sap become very slight; and the leaves begin to die. It is partly that they are in some measure worn out by the summer's work, just as the bees are; it is partly that the outer world has changed. It is well that they should die, lest they begin to undo what they have so well done.
>
> But before they die they surrender to the plant that bears them all the residue of their industry that is worth having. There is a gentle current of sugar and other valuable materials from the dying leaf into the stem before the breath of approaching winter.
>
> Virtually dead the leaves now are, empty houses, all dismantled, with little more than ashes on the hearth. But these ashes—how glorious! for in yellow and orange, in red and purple, in crimson and scarlet, the withering leaves shine forth. They are transfigured in the very article of death, in the low beams of the autumn sun. The yellowness is often due to the breaking up of the green colouring matter called

chlorophyll; the brighter tints are due to the presence of special pigments, which are by-products or waste-products of the leaf's intense life.

Finally, the leaves fall gently from the trees, or, after writhing and rustling in the wind, as if loath to be separated, are violently wrenched off and whirled along the ground. But the tree is not really impoverished by the yearly loss of its leaves, while they, on the other hand, weathered, faded and torn, and mouldered by fungi, are buried by earthworms, to form, with the help of bacteria, the vegetable mould in which are cradled the seedlings of another year.

BIBLIOGRAPHY

Bose, *Life Movements in Plants.*
Bower, *Botany of the Living Plant* and *Plant Life on Land.*
Darwin, *Insectivorous Plants* and *Movements and Habits of Climbing Plants.*
Farmer, *Plant Life.*
Geddes, *Chapters in Modern Botany.*
Harvey-Gibson, *Outlines of the History of Botany.*
Herrick, *Wonders of Plant Life.*
Jones and Rayner, *Plant Biology.*
Kerner and Oliver, *Natural History of Plants.*
Müller, *Fertilisation of Flowers* (translated by D'Arcy Thompson).
Scott, *Evolution of Plants.*
Timiriazeff, *The Life of the Plant.*

XVIII

INTER-RELATIONS OF LIVING CREATURES

INTER-RELATIONS OF LIVING CREATURES

THE BALANCE OF NATURE—THE WEIRD WAYS OF PARASITES

MANY naturalists have had the vision of "the web of life," but none so vividly as Darwin. It was central in his picture of Animate Nature. By "the web of life" we mean that no creature lives or dies to itself; that each life is linked to other lives, often in obscure and unsuspected ways. Everything, as the philosopher Locke put it, is a retainer to other parts of the vast system of Nature.

Balance of Nature.

We have seen that green plants feed on air, water, and dissolved salts; that by utilising the energy of the sunlight they are able in the laboratory of the leaf to build these up into compounds; and that on these products all animal life depends, either directly in the case of vegetarian animals or indirectly in the case of carnivores. There is a deep biological sense in which all flesh is grass. This is one aspect of the Balance of Nature, that there must be sufficient vegetable materials in an area to keep the animals agoing.

Another aspect of the Balance of Nature has to do with oxygen and carbon dioxide. Few people realise that the bulk of the oxygen in our atmosphere has been formed by green plants, which in the daylight are always splitting up carbonic acid gas and liberating oxygen into the air. This oxygen is used by animals, and by plants as well, for keeping up the oxidation or combustion of carbon compounds which living always implies.

Nutritive Linkages

The system of Animate Nature involves nutritive chains, one creature being dependent upon another for sustenance. Animals eat plants or other animals, or, in some cases, what plants and animals have made, e.g. fallen leaves and stored honey. In any case, there is a continual circulation of matter from one embodiment to another. There is an endless cycle of incarnations. The codfish eats the whelk, the whelk devours marine worms, worms feed on the sea dust—meaning by that the microscopic organisms that swarm in the waters. A cartload of bracken is tumbled into a loch; it is acted on by bacteria which break it down into particles and simpler substances; on these and on the bacteria themselves myriads of infusorians feed; these in turn are devoured by small crustaceans, and these are devoured by trout. It is very important for practical purposes to discover these nutritive chains.

The most insignificant plants and animals often play an important part in the economy of nature, or what we call the Balance of Life. Thus earthworms may seem to form a "despicable link in the chain of nature," yet they are all-important. Vegetation would fare ill without them. How well Gilbert White (1777) appreciated their importance!

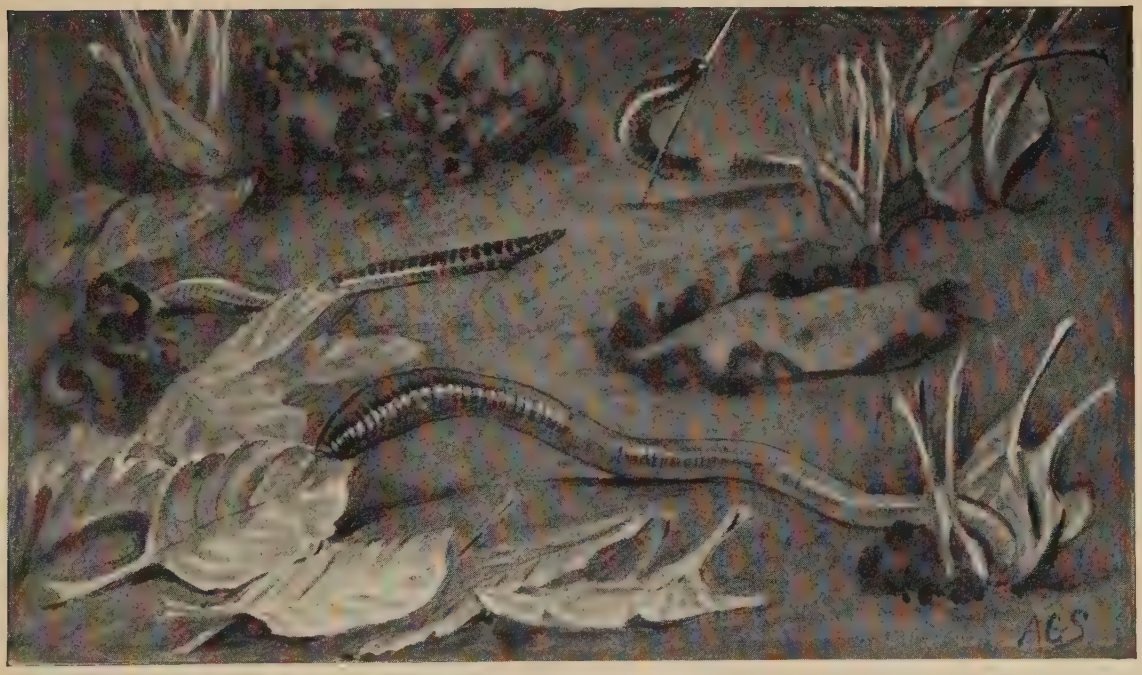
> Earthworms, though in appearance a small and despicable link in the chain of Nature, yet, if lost, would make a lamentable chasm. Worms seem to be the great promoters of vegetation, which would proceed but lamely without them, by boring, perforating, and loosening the soil, and rendering it pervious to rains and the fibres of plants, by drawing straws and stalks into the soil; and most of all by throwing up such infinite numbers of lumps of earth. . . . The earth without worms would soon become cold, hard-bound, and void of fermentation, and consequently sterile.

When he was a young student in Edinburgh, Charles Darwin began studying the work of earthworms, counting the num-

Photo: J. J. Ward.

BRANCHED HAIRS FROM THE BODY OF A HUMBLE-BEE, WITH POLLEN-GRAINS ENTANGLED

The pollen, with which the humble-bees become dusted on their visits to the flowers, is used as food, and is often stored in special "pollen-tubs" within the nest. But in securing pollen for themselves the bees carry some of the grains from one blossom to another blossom of the same kind. Thus pollination is effected in "bee-flowers."



EARTHWORMS AT WORK

The agricultural activities of earthworms are fourfold. They bruise the earth in their gizzards and make soil-solution easier. They make burrows which aerate the soil and open it up for rootlets and rain. They bury the surface with the castings which they bring up, turning the soil round and round in the course of time. They also bury leaves, some of which are eaten, while others rot away into vegetable mould. Darwin noted that they often deal with leaves in a very effective way; but in cases where they drag down feathers their "instinct" is probably working somewhat "blindly."

Reproduced from Fabre's "The Wonders of Instinct."

A BURYING-BEETLE EXPERIMENT

A dead mouse is placed on the branches of a tuft of thyme. By dint of jerking, shaking, and tugging at the body, the Burying-beetles succeed in extricating it from the twigs and bringing it down.

Photo: J. J. Ward.

A FLOWER-HEAD OF CLOVER, SHOWING HOW THE FLORETS TURN DOWN OUT OF THE WAY AFTER THEY ARE POLLINATED OR FERTILISED BY THE VISITING BEES

The fourth flower-head shows only one floret left upstanding. In the last flower-head they have all turned down. Of all the linkages in the web of life this inter-relation between flowers and their appropriate visitors is perhaps the most important.

ber of holes in measured areas, weighing the castings brought up on sample square yards, and estimating the number of leaves they took down into their burrows. With his characteristic patience he continued the study all his life, and it was not till 1881, the year before he died, that he published his remarkable book *The Formation of Vegetable Mould through the Agency of Earthworms,* which proved that earthworms have made the bulk of the fertile soil of the globe.

Let us take three or four of his statistics. In an acre of British soil there are on an average 53,000 earthworms, and in fine old fallow ground there may be half a million. On an average, they pass 10 tons per acre through their bodies in a year, and they have been doing this for many millions of years. With their castings they cover the surface at the rate of 3 inches in 15 years, and they are thus continually circulating the soil—an age-long ploughing field which was so thickly covered with hard flints that it was known as "the stony field" was left untouched for thirty years, after which, we are told, a horse could gallop from one end to another without ever striking a stone.

Darwin sums up:

> When we behold a wide, turf-covered expanse, we should remember that its smoothness, on which so much of its beauty depends, is mainly due to all the inequalities having been slowly levelled by worms. It is a marvellous reflection that the whole of the superficial soil over any such expanse has passed, and will again pass, every few years, through the bodies of worms. The plough is one of the most ancient and most valuable of man's inventions; but long before he existed the land was, in fact, regularly ploughed by earthworms. *It may be doubted whether there are many other animals which have played so important a part in the history of the earth as have these lowly organised creatures.*

Earthworms are thus great promoters of vegetation. They also play their part in the disintegration of rocks, letting the

solvent humus-acids of the soil down to the buried surface. Their castings on the hill-slopes are carried down by wind and rain and go to swell the alluvium of the distant valleys.

Linkages Securing Survival

The most important linkage in the world is that between many flowering plants and their insect visitors, as we have seen (see BOTANY). The insects carry the fertilising pollen from one blossom to another and bring about not merely fertilisation but cross-fertilisation, which increases the yield and the quality of the seed. Unless the egg-cell, inside the ovule inside the ovary of the flower, be fertilised by a male nucleus from the pollen-grain, the possible seed will not become a real seed capable of development or germination. Some flowers, like peas, are self-pollinating; in some other cases, like pine-trees, the pollen is carried by the wind, but most flowers are cross-pollinated by insects, and it has been proved experimentally that cross-pollination is best.

Cats and Clover

In illustrating the linkage between flowers and their *welcome* insect visitors (for there are others that do nothing but harm), Darwin told the "cats and clover" story, which soon spread round the world. Round a hundred heads of the purple clover he put muslin bags, so that air got in and sunlight got in, but no insects. From these hundred heads he got not a single real seed, while from another hundred heads without muslin bags he obtained 27,000 seeds. These heads had been visited by the humble-bee, which effects cross-fertilisation. So the more humble-bees the better next year's clover crop.

But the nests of the humble-bees are rifled by the field-mice or voles, which are fond of the delicate white grubs. Therefore, the more field-mice the fewer humble-bees, and the poorer next year's clover crop.

But in the neighbourhood of villages there are fewer field-

mice than in the open country, for the cats hunt them down, killing them though they do not eat them. Therefore, the more cats the fewer field-mice, and the fewer field-mice the more humble-bees, and the more humble-bees the better next year's clover crop. It is easy to extend these "House-that-Jack-built" stories. The more clover the richer the pasture for the cattle, and the more roast beef for John Bull. The more kindly old ladies there are in the village the more cats there will be, and this again will favour the clover! Thus cats and clover and cattle are linked together.

It has been stated that in some instances the purple clover has seeded satisfactorily in the absence of humble-bees. This may be due to the occurrence of self-pollination or to the visits of some other insect which fills the humble-bee's röle as pollinator. But the main fact is well illustrated in the case of a country like New Zealand.

The Case of Red Clover

When the farmers there first tried to cultivate the purple or red clover, it failed to produce seeds, for there were no humble-bees in the islands. Bees were introduced and they multiplied apace; the raising of clover-seed became commercially profitable. A subsequent importation of American species of humble-bees with longer tongues, readily able to reach far down into the floral tube, was followed by further improvement in the yield of clover-seed. In one province, in 1912, an area of 610 acres was sown with red clover and yielded an average of 158 pounds to the acre.

Distribution of Seeds

Hardly less important than the pollination of flowers is the distribution of seeds, and again we may begin with a classic case from Darwin. When birds get their feet wet, clodlets of earth often form on them, and these may include the seeds of plants, and, besides these, small animals or their larval stages. When the

bird gets its feet washed clean at some other place the seeds are liberated from the clodlets, and thus there is scattering of seeds.

> Many facts [Darwin writes] could be given showing how generally soil is charged with seeds. For instance, Prof. Newton sent me the leg of a red-legged partridge (*Caccabis rufa*) which had been wounded and could not fly, with a ball of hard earth adhering to it, and weighing six and a half ounces. The earth had been kept *for three years,* but when broken, watered, and placed under a bell glass, no less than 82 plants sprung from it: these consisted of 12 monocotyledons, including the common oat, and at least one kind of grass, and of 70 dicotyledons, which consisted, judging from the young leaves, of at least three distinct species.[1]

When a bird is killed and rots away on the earth, or is buried by sexton-beetles, the undigested seeds in its crop may, similarly, be sown far from where they were gathered.

Ants and Seeds

Ants are particularly fond of seeds which have "oil-bodies" or "food-bodies" on their coats, e.g. violet, bluebell, mignonette, and fumitory. In some cases they eat only the external "food-body," so that the seeds thrown out from the ants' nest may still germinate. Moveover, in many cases the seeds are lost by the ants as they are carrying them home. Professor F. E. Weiss placed the seeds of gorse and broom, which have very distinct food-bodies, on the ants' tracks, and found that they were soon picked up, while the seeds of various other plants were left alone. It is reasonable, therefore, to conclude that ants assist in the distribution of gorse and broom.

§ 1

Freshwater Mussels and Minnows

Another example of the way in which one creature depends on another for the continuance of its kind may be found in the

[1] *Origin of Species,* p. 328.

Photos: J. J. Ward. 1 2

RIPE FLOWER-HEAD OF THE GOAT'S-BEARD (*Tragopogon pratensis*)

(1) Ripe flower-head of the Goat's-beard (*Tragopogon pratensis*) commencing to open. The flower-head in composite flowers, such as dandelion and thistle, consists of numerous florets. At the base of each is a nutlet-like ovary, and in this, after pollination, a seed develops. On each nutlet there grows a tuft of hairs (pappus), which serves as a parachute when the fruits are ready to be scattered by the wind. In the Goat's-beard the hairs of the so-called pappus are hygroscopic, changing their position according to the moisture in the air. (2) Ripe flower-head of the Goat's-beard a day later.

3 4 5

(3) Ripe flower-head of the Goat's-beard on the third day. (4) Ripe flower-head of the Goat's-beard on the fourth day. (5) Ripe flower-head of the Goat's-beard fully expanded with the fruits ready to be floated away by the wind and thus sown, often at a distance. As the flower-head is in process of ripening moist weather affects the pappus hairs in such a way that the whole inflorescence closes up and is thus kept dry. Each parachute is like dandelion-down, beautifully constructed, and obviously suited for aerial transport.

Photo: F. R. Hinkins & Son.

DRY FRUITS OF HONESTY (*Lunaria biennis*)

The seeds of this plant are scattered by the wind, and this is facilitated by the delicate, translucent, papery membranes to which these seeds are attached. Two of the seeds are seen in the photograph as dark disks.

THE CROCODILE-BIRD AND ITS REPTILIAN PARTNER

In this quaint external partnership the bird is benefited because it eats leeches and other parasites which it finds about the Crocodile's back and mouth. The Crocodile is benefited because the bird is very wary and flies away with loud cries when any danger threatens.

linkage between freshwater mussels and minnows. The eggs of the freshwater mussel are produced about midsummer in Britain, but they are not set free. They develop in a special brood-chamber, the cavity of the basketwork-like outer gill. They turn into pin-head bivalve larvæ called Glochidia, which are not allowed to escape till early in the following year. Moreover, *they are not liberated unless a fish such as a minnow comes swimming slowly* past. When the larvæ are set free they swim in the water clapping their valves together, exuding delicate gluey threads, and making for the fish. Some lucky ones get attached to the minnow and burrow a little into the flesh. Here they undergo a great change and eventually drop off into the mud, often far from where they were born. It is very striking to find that a Continental fish, the bitterling (*Rhodeus amarus*), uses a long egg-laying tube to inject its eggs into the freshwater mussel. The eggs develop in the mussel's gill-chamber, and the larval bitterlings spend some time there before they find their way out. So the freshwater mussel is dependent on some fish, and the bitterling is dependent on the freshwater mussel! This is what is meant by linkage, and scores of striking instances will be found in books that deal with life-histories.

One Creature on Another

It often happens, especially in a crowded area such as the sea-shore, that one animal settles down on the back of another, as rock-barnacles on a crab's shell or a tube-inhabiting worm on a buckie. This mode of life is called epizoic, and it may be adopted by plants as well as by animals. Thus seaweeds are often attached to crabs and even to aged lobsters, and a green Alga grows on the shaggy hair of the tree-sloth. It may be an advantage to the epizoic animals or plants to be carried about by an active bearer. To the bearer it is probably in some cases a burden; but it is often quite indifferent; occasionally, as has been noticed in the article on Disguise, it has a camouflaging utility.

There is a vivacious plover that lives in an interesting partnership with the crocodile, as Herodotus reported long ago.

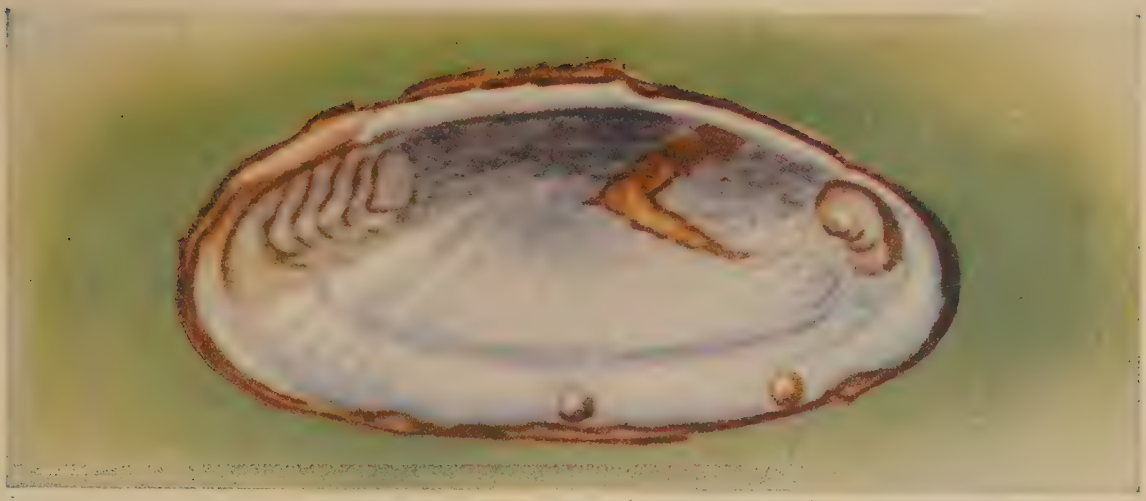
> Observant, inquisitive, excitable, clamorous, and gifted with a far-reaching voice, it is well fitted to serve as watchman to all less careful creatures. No approach, whether of beast of prey or of man, escapes its suspicious observation; every sailing-boat or rowing-boat on the river attracts its attention; and it never fails to tell of its discovery in loud cries.[1]

This sentinel is at home on the sandbanks on the Nile where the crocodiles are wont to rest. It often perches on the reptile's back, from which it picks leeches, and it will even jerk a morsel of food from between the teeth. Dr. Leith Adams writes that the Egyptians of to-day have put a tail to the account that Herodotus gave of the partnership.

> They say, that in addition to its office of leech-catcher to the crocodile, it occasionally does happen that the zic-zac—so called from its note of alarm—in searching for the leeches, finds its way into the reptile's mouth when the latter is basking on a sandbank, where it lies generally with the jaws wide open. Now this is possible and likely enough, but the captain of our boat added, that occasionally the crocodile falls asleep, when the jaws suddenly fall, and the zic-zac is shut up in the mouth, when it immediately prods the crocodile with its horny spurs, as if refreshing the memory of his reptilian majesty, who opens his jaws and sets his favourite leech-catcher at liberty.[2]

There seem to be two of these crocodile-birds, both plovers, the black-headed *Pluvianus ægyptius* and the spur-winged *Hoplopterus spinosus*. This case must serve in illustration of partnership, but we may mention the small horse-mackerels that sometimes swim about under the shelter of a big jellyfish's umbrella, the beef-eater birds that perch on cattle and clean their

[1] Brehm's *From North Pole to Equator.*
[2] *Notes of a Naturalist in the Nile Valley,* 1870.



Reproduced from "The Wonder of Life" by Professor J. Arthur Thomson (Andrew Melrose, Ltd.).

ONE VALVE OF THE FRESHWATER MUSSEL

This bivalve lives a sluggish life in rivers and ponds. Its two shell-valves, one to the right and the other to the left of its body, are very solidly built of carbonate of lime and an organic substance called conchin. To the outside there is a layer without any lime, then a thick layer with lime arranged in prisms, and then innermost the mother-of-pearl layer with iridescent colouring. The shell is always being added to at the margin, as the animal grows bigger. It shows concentric lines of growth. Several fixed pearls are seen near the margin (see above illustration), but really fine pearls lie embedded in skin-pockets of the mollusc. Truly fine pearls are believed to be formed (*a*) in some cases around the larva of a parasitic worm, and (*b*) in other cases around a minute blob of conchin. The larvæ of the freshwater mussel have to spend a short time as temporary parasites on a freshwater fish.

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A HIGHLY EVOLVED ORCHID

(*Odontoglossum crispum*)

Many of the Orchids deserve to be called the aristocrats of the floral world. They are beautiful in form and colouring and fine in fragrance, and they have a strong individuality. Their arrangements in connection with the visits of insects are often highly specialised; and Darwin, who made a careful study of their pollination, notes that "a study of their many beautiful contrivances will exalt the whole vegetable kingdom in most persons' estimation." It is a case of flower and insect being fitted as glove and hand. While the Orchids of temperate countries always grow in the ground, in meadows and woods, many of those which are found in warm and moist countries live as "epiphytes," perched on the stems and branches of trees. Their aerial roots have a spongy outer envelope which readily absorbs water and also air laden with water-vapour. In Odontoglossum there is a partner filamentous fungus which lives in the outer part of the root, and a striking fact is that some of the cells of the Orchid-root digest the fungus and seem to keep it from [illegible]. It will be understood that epiphytic Orchids are not parasites on the trees; they are simply perched plants.

hide, and the pilot-fish that accompanies the shark. There is nothing hard and fast in our grouping of these associations, and what we have called partnership passes insensibly into something more definite. Thus the little tiny pea-crab often lives within the horse-mussel, finding shelter and apparently food as well.

It is naturally difficult to draw a firm line where shelter stops and some sort of co-operation begins. There is a brilliant Indian Ocean fish, about two inches long, called Amphiprion, that lives in association with a large reef-anemone (Discosoma). It lives among the tentacles of the anemone and retires into the food-cavity on the slightest alarm. It dies when it is removed from the sea-anemone. As Mr. Banfield says in his delightful *My Tropic Isle* (1910), "it is almost as elusive as a sunbeam, and most difficult to catch, for if the anemone is disturbed it contracts its folds and shrinks away, offering inviolable sanctuary." The benefit to the little fish is plain enough—it finds shelter and crumbs; but is there any benefit on the other side? Many sea-anemones are in the habit of stinging and seizing small fishes which intrude inquisitively or incautiously, but Discosoma does not seem to do this to Amphiprion. It has been suggested that the brilliantly coloured fish serves as a lure; it seems more likely that the movements of the fish in and about the sea-anemone keep up useful currents of water.

§ 2

Commensalism

In a previous section reference has been made to an external partnership, mutually beneficial, between two quite different kinds of animals, which is usually spoken of as "commensalism," —meaning eating at the same table (*con*, together, and *mensa*, a table): the word is almost the same as companionship (eating the same bread). Fine instances are found in the associations between hermit-crabs and sea-anemones. Certain kinds of hermit-crabs place sea-anemones on the back of the buckie or other shells

which they have commandeered for the shelter of their flabby tails. There may be three or more sea-anemones on the top of a big shell. The advantages to the hermit-crab are that the anemones mask its real nature and that they can sting. In certain crabs a sea-anemone is actually fixed on each of the great claws, as if the crustacean made a weapon of the polyp. The advantages to the sea-anemones are that they are carried about and that they get morsels from the hermit-crab's meals, which are many. In this mutually beneficial partnership there are several points of much interest. Thus a hermit-crab deprived of its partner was seen to stalk about restlessly, ill at ease until it obtained another of the same kind. When a hermit-crab has grown too large for its borrowed shell it has to flit. This means leaving the sea-anemones behind, but the hermit-crab has been seen removing them from the relinquished shell and establishing them on the new one. A sea-anemone removed from its partner was seen, after a while, to fasten itself to the leg of a passing hermit-crab and gradually move on to the top of the shell. In certain cases the sea-anemone is never seen apart from the hermit-crab, and vice versa.

Getting away from marine animals, we may notice that associations which may be called commensalism are well known among insects. Thus Mr. William Beebe has recently described a minute blind cockroach (Attaphila) that lives in the subterranean nests of the Atta leaf-cutter ants. They clean the bodies of the giant soldier-ants and seem to do no harm in the nest. We need not refer to other instances of commensalism which have been mentioned elsewhere in this work. We have also had occasion to refer to examples of symbiosis.

Symbiosis

The term symbiosis, which simply means living together (*syn,* together, and *bios,* life), has been earmarked for mutually beneficial internal partnerships between two organisms of different kinds. Thus a green Alga lives inside the little marine

worm called Convoluta, and makes the worm a sort of plant-animal, and a very successful association it is.

The Double Life of Lichens

It was the great botanist De Bary who first applied the term symbiosis to the partnership illustrated by those strange encrusting plants called lichens which are so familiar on trees and rocks. They are even stranger than they look, for they are double-plants, as we have seen (see p. 610).

It is impossible not to be interested in lichens, pioneers in soil-making, sheltering and feeding those animals that are the outposts of life's ceaseless campaign, but is not their supreme interest that they represent a very distinctive adventure in evolution—the adventure of symbiosis?

The Seamy Side of Heather

Everyone knows that heather grows well on poor and unpromising soil where relatively few other plants will thrive. The water of the moorland is apt to be in such an acid state that the roots of plants cannot use it. The nitrogenous supplies in the soil are unavailable because bacteria do not flourish in peaty environment. The same is true of earthworms, which make soil elsewhere. What, then, is the heather's secret, for it certainly thrives on mountain and moorland? It has a partner-fungus that sends its threads or hyphæ not only into the cells of the root, but through and through the stem and leaves, and even into the seed-box. The fungus acts as the intermediary between the heather and the soil; it absorbs water and organic material; it is perhaps able in some measure to fix atmospheric nitrogen. In any case, the heather has been able to effect a compromise with what was probably, to start with, a predatory intruder; indeed, the compromise has gone so far that the heather cannot thrive without its partner. As Dr. Rayner says, the heathers "have solved the problem of growth on poor and unpromising soils, but have solved it at the price of their

independence." The infection of the heather seems to take place shortly after the germination of the seeds, and it is a remarkable fact that the seedlings do not develop roots in a pure sterilised culture where there is no partner-fungus. But infection with the right fungus brings about normal development. *The heather's health and continuance depend on its symbiosis with a Fungus.* More information in regard to these partnerships will be found in the article on BOTANY.

§ 3

Man and the Web of Life

If the world of living creatures is a vast interlinked system, the fact must be carefully appreciated by everyone who would operate on Animate Nature, and that is what Man is always doing. If he is to control Nature, he must first know and then respect the web of life. By ignoring it or defying it, Man has brought much trouble upon the earth. Let us consider some illustrations of his mistakes and of his achievements.

1. Man is a distributor of plants and animals. About 1860 he took rabbits to Australia, and there, in the absence of their natural enemies, these adaptable creatures multiplied excessively and turned vast areas of fertile country into barren desert. Over a dozen times the European sparrow was introduced into the United States, partly in the hope of checking the elm-tree caterpillars. This it did in some measure, but only to become itself a greater pest, doing much damage to the crops and driving away native insectivorous birds. The annual cost to the States amounts to a prodigious sum.

Of course, man is not always doing such stupid things. He imports fruit-trees into South Africa and wheat into America; he establishes turkeys from Mexico in Europe and sheep from Scotland in New Zealand. It must be noted, however, that his successes have been greatest with domesticated animals and cultivated plants, over which he had previously established some control.

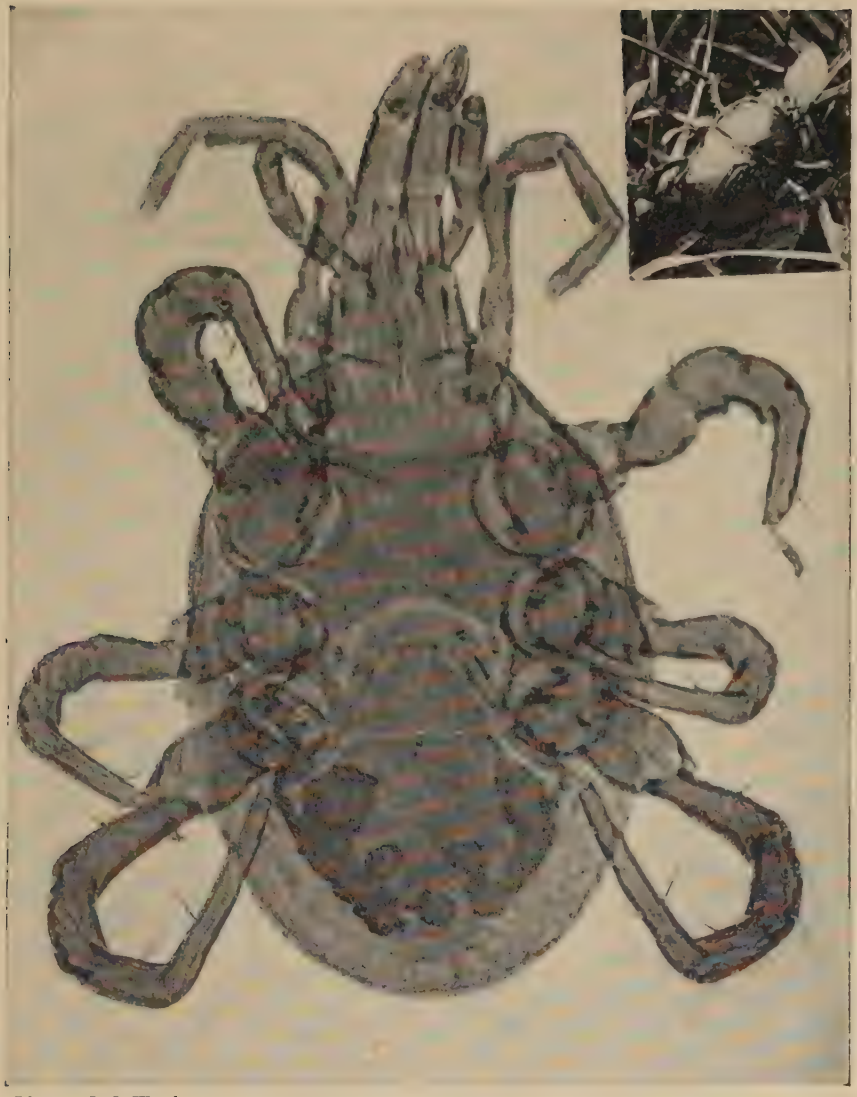


Photo: J. J. Ward.

THE MITE (GAMASUS) THAT IS CARRIED ABOUT BY THE DOR BEETLE (GEOTRUPES) (shown in the upper inset.)

There may be over a score on one beetle, moving about and hanging on by means of their four long curved and clawed legs. The photograph shows the under surface of the mite. As usual there are two pairs of mouth-parts, the nipper-like cheliceræ and the pedipalps. This mite is blind.

Photo: F. R. Hinkins & Son.

A COMMON BRITISH LICHEN (*Evernia Prunastri*)

It grows on trees and old palings, and is greenish-grey above, white beneath, with strap-like branched fronds. The fungus partner absorbs the rain-water and may get something in the way of inorganic salts from the surface of its support. The alga partner, which consists of green cells, manufactures carbohydrates. These are utilised by the fungus.

2. Man has sometimes brought about very unfortunate results by encouraging, rather than directly extending the range of certain living creatures. Thus by careless and unthrifty ways of dealing with refuse and crumbs of all sorts, he has encouraged the multiplication of rats to an extent that is ominous, to say the least. Many millions of brown rats are at present being supported in Britain alone, and the damage is not confined to the destruction of all sorts of stores; they foul much more than they eat. Furthermore, they harbour a dangerous human parasite, *Trichinella spiralis,* which has the pig as its second host, intermediate between rat and man. Again, the microbe (*Bacillus pestis*) of the bubonic plague of India, once known as "the black death" in Britain, is more or less at home in the rat, and is imbibed by the rat-flea along with its meals of rat's blood. From a dead rat the fleas jump away, and an infected flea may inoculate a man with the bacillus of the plague. Nothing could better illustrate the intricacy of inter-relations, and the instance becomes still more picturesque when we notice the report that plague is distinctly less frequent in those Indian villages that abound in cats. For the more cats the fewer rats, and the fewer rats the fewer rat-fleas, and the less plague.

3. In many cases man's disturbance of the Balance of Nature is just the tax that has to be paid on a laudable achievement. The potato-beetle, or Colorado beetle (*Doryphora decemlineata*), which has occasionally shown face in Britain, used to be restricted to the central west of North America, where it fed on the deadly nightshade, and did not multiply greatly, being kept in check by natural enemies. But the introduction of the potato plant (a relative of the deadly nightshade) and the great extension of potato-fields year after year gave the beetle a chance for prolific multiplication. It spread gradually eastward, and its enemies could not any longer keep it in check. Year after year it continued its eastward march until it reached the Atlantic seaboard. Many counteractive methods have been tried, but the Colorado

beetle remains unconquered, and continues to levy a very serious toll. Yet no one can say that man was much to blame.

4. Occasionally man's knotting of the web of life is accidental, as in the diagrammatic case of the Gipsy Moth (*Ocneria dispar*), which a naturalist, Trouvelot by name, imported about 1869, for some scientific purpose, from Europe to Massachusetts. By an accident some of the caterpillars got free, and although Trouvelot did all he could to avert the consequences he did not succeed in retrieving all the escapes, and the Gipsy Moth "caught on." Along with another introduction, the Brown-tail Moth, it continues unconquered to do terribly destructive work in defoliating trees in the States.

But let us look at a brighter picture. In his valuable book on *Organic Evolution* (1917) Professor R. S. Lull writes:

> One instance where Nature's balance has been restored after being upset by human interference is in the case of a scale insect accidentally introduced into California from Australia on some young lemon-trees. This multiplied until it became a most pernicious pest which various mechanical remedies failed to control. Search was made in Australia, and a natural enemy, a lady-bug, was brought over to California, with the result that the scale was not only reduced but almost completely eliminated. It was then found that the lady-bug depended upon the scale for food to such an extent that it died in turn, and now protected colonies of scale insect and lady-bug are kept in readiness to control future outbreaks of the pest.

This importation of a natural enemy to counteract the destructiveness of an introduced alien has been tried in a number of cases with great success.

5. Sometimes man disturbs the Balance of Nature by eliminating, not by fostering.

> There is an Australian story which reads as if written for our instruction. On certain Murray River swamps

Photo: J. J. Ward.

FEMALE FLEA OF RAT (Magnified 50 diameters.)

The flea is a wingless insect, with great powers of leaping, as the length of the legs suggests. Unlike most insects it is much taller than it is broad. The male is much smaller than the female. The eggs are laid in crevices, and there the metamorphosis, through larva and pupa stages, is accomplished. The larva eats fragments of organic matter. When an adult flea bites man it injects a secretion from its mouth, and this sets up irritation. But the piercing mouth-parts may have been contaminated with microbes, and these increase the irritation or may produce disease. Thus when the rat-flea of warm countries has been biting a rat whose blood contains the bacillus of the plague, it may proceed to bite man and infect him.

The drawing well illustrates the ceaseless struggle of kind against kind. A fly is seen flitting over the surface of the river; a small fish jumps up to capture the insect. Behind and below a pike has its eye on the small fish, but he is anticipated by a kingfisher, which snatches the small fish and robs the pike of its prey. Above, a hawk poises itself ready to swoop down on the successful kingfisher, which, perchance, in its turn becomes the victim.

several species of cormorants used to swarm in thousands, but ruthless massacres, ordered on the supposition that the birds were spoiling the fishing, reduced them to hundreds. But the fishing did not improve; it grew worse. It was then discovered that the cormorants fed largely on crabs, eels, and some other creatures which devour the spawn and fry of the desirable fishes. Thus the ignorant massacre of the cormorants made for the impoverishment, not for the improvement, of the fishing. The obvious moral is that man should get at the facts of the web of life before, not after, he has had recourse to drastic measures of interference with the webs of life.[1]

The Importance of Birds

One of the risks to which the Balance of Nature is exposed is the multiplication of insects. There are so many of them and they are so prolific. Their over-population is often disastrous for a time in a limited area, as is familiar in an invasion of locusts; but this is obviated as a worldwide catastrophe by the changeable weather and by insectivorous animals. Among these the place of first importance must be given to insect-eating birds. It is not possible to make precise calculations, but some experts have said that *six to ten years without birds would suffice to bring our whole system of Animate Nature to an inglorious end*—a vast hecatomb of insects—devouring and smothering one another. This is the biological reason for opposing the destruction of insect-eating birds except under careful scrutiny. That they are irreplaceable masterpieces of beauty is another reason of a different order but not less cogent.

One cannot pretend that the question of elimination is easy; one can only plead that wholesale massacres should not be permitted without the most careful consideration. Poisonous snakes are proscribed, but is it clearly understood that their destruction implies a multiplication of mice and other "vermin"

[1] Thomson in Dendy's *Animal Life and Human Progress*, 1919, p. 88.

on which many snakes feed? Anti-squirrel clubs have been started because of the damage done to young trees. A price is put on the beautiful rodent's head, and the heads come tumbling in. Sometimes, however, the squirrel club has had to be dissolved, because of the over-multiplication of wood-pigeons, which eat enormous quantities of grain, and may mean a serious loss to the farmer. The usually vegetarian squirrel levies toll on the young squabs of the wood-pigeon.

Just as man encourages rats without wishing to, so he discourages wild things without meaning to. Agriculture spreads; marshes are drained; forests are cleared; the stretch of wildness becomes a trim golf-course. Therefore the wild cat becomes a rarity, and the pine-marten disappears; the bittern becomes scarce, and the ruff has all but ceased to nest in Britain. "One hopes, however, that there is a fresh growth of a vivid and determined awareness that creatures like bitterns and badgers are national treasures of real value, not to be sacrificed any longer either to ignorance or to greed."

§ 4

A Multitude of Linkages

Sir Ray Lankester has summarised the numerous practical relations between man and animals, and it is instructive to consider their manifoldness: (*a*) We capture animals for the sake of their flesh, e.g. hares and rabbits, herring and whitebait. We kill others for parts that are not edible, the whale for its oil and whalebone, the pearl-oyster for its pearls and mother-of-pearl. (*b*) Other animals are bred for utilitarian reasons, e.g. pigs for their flesh; cattle for flesh and milk; horses for transport; dogs for their watchfulness; turkeys, geese, and poultry for the table; bees for their honey; silk-moths and sheep for raiment; and so on. Sometimes the utility is æsthetic, as in the case of canaries and goldfish. The keeping of pets, from cats to white mice, from parrots to poodles, may be included here. (*c*) Then there are those animals

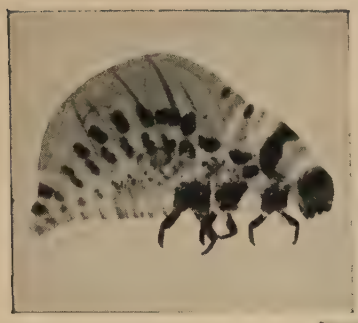


Photo: J. J. Ward.

LARVA OF COLORADO BEETLE—ENLARGED

Out of the egg of the potato-beetle (*Doryphora decemlineata*) there comes a reddish "hard grub," with strong head and legs, active habits, and a large appetite. The posterior part of the body is very convex above. After feeding on the potato leaves for a fortnight or so, the larvæ become yellow pupæ in the ground. From the pupa in about ten days the beetle emerges. About a month altogether is required for the development of the egg into a perfect beetle. Thus there may be 2–4 broods in a season. The adults spend the winter in a resting state underground.

Photo: J. J. Ward.

COLORADO BEETLE ENLARGED AND DISPLAYED TO SHOW THE WINGS AND THE WING-COVERS

The adult female is a little under half an inch in length. There are five longitudinal stripes on each wing-cover, and to this the name *decemlineata* (10-lined) refers. The female lays 500–1,000 eggs in a season; 10–40 at a time, in clusters on the under side of the potato-leaves. Before the cultivation of the potato was extended westwards in North America, the potato-beetle fed on a kind of nightshade or sand-bur (*Solanum nostratum*) belonging to the same genus as the potato. The beetle began spreading about 1859, and by 1874 it had reached the Atlantic coast in many places—which meant an average annual rate of about 88 miles.

Photo: J. J. Ward.

GIPSY MOTH (*Ocneria dispar*)

The male above, the female below. This European Moth was introduced by accident into North America about 1869; it has gradually multiplied to a very serious extent, and remains an unconquered pest. The caterpillars defoliate the trees. A near relative of the Gipsy Moth is the Nun, which is very destructive in some European forests.

Photo: W. E. Berridge.

THE WILD CAT

The Wild Cat (*Felis catus*) is the only wild representative of the Cat tribe in Britain; but it is now very rare. It lingers only in remote parts of Scotland. It is not to be mixed up with the Polecat, which belongs to the Bear tribe, nor with certain domestic cats which have become wild or "feral." From the domestic cat it differs in its proportionately longer body and limbs, and in its shorter and thicker tail, which does not taper. In all probability the domestic cat is a descendant of the Egyptian Cat (*Felis caffra*).

THE PINE-MARTEN

The Pine-Marten (*Mustela martes*) is a member of the Bear tribe. The length of the head and body is about 18 inches, and the tail is almost a foot long. There is long brownish outer fur and short yellowish-grey under-fur. The Marten is a lithe, alert, courageous carnivore but in Britain it is now even scarcer than the Wild Cat.

that help man's endeavours. The earthworms have largely made the fertile soil, and the humble-bees pollinate the clover. The fisheries are after all dependent on the multitudes of minute crustaceans in the sea-soup, and these on the microscopic Infusorians and Algæ. (*d*) But there are other animals that hinder man's operations and baulk his experiments. The poisonous snake bites his heel, and the mosquito infects him with yellow fever. In some places the midges are so rampant that life becomes a burden, and the heaviest cloud of depression and despair that has ever rested on the human race is due to a contemptible threadworm —the Hookworm—whose larvæ enter man's skin from the fouled soil. A knowledge of the life-history of the intruding parasite is now making it possible, however, to check its deplorable ravages. Long ago in man's history the enemies that counted for most were large creatures, such as lions and tigers, wolves and bears; but nowadays most of man's serious enemies are minute, we may even say microscopic. (*e*) Besides those animals that directly hinder man there are the multitudinous enemies of his flocks and herds, his farms and gardens. The field-voles are sometimes "plagues"; the wood-pigeons devour good seed; the Phylloxera spoils the vineyards; the Colorado beetle ravages the potato crop; the number of injurious insects is legion. Man's domesticated animals are attacked by numerous parasites: the horse has its "bots," the cattle their "warbles," the sheep their "sturdie," and the pig has an internal menagerie. (*f*) Others, again, attack man's permanent products and his stores. In warm countries the white ants or termites make sawdust of everything wooden, and imply a considerable check on many of man's operations. Also very serious are the grain-weevils that do much harm in granaries, and rats are worst of all. Bookworms and clothes moths can be readily checked, but it is a more difficult problem to cope with cockroaches. (*g*) Finally, there are those very useful animals which help to keep down those mentioned in the last three sections (*d*, *e*,

and *f*), the hedgehogs that devour the slugs, the lapwings that prey upon the wireworm, the lady-birds that check the prolific green-fly, and the ichneumon flies that lay their eggs in caterpillars.

Reference has already been made in the article, Evolution Going On, to Dr. James Ritchie's masterly book, *The Influence of Man on Animal Life in Scotland* (1920), wherein it is shown with scholarly precision what changes have been wrought in a few thousand years by man's domesticating and destroying, introducing and eliminating, preserving and cultivating. The outstanding lesson is surely that no creature lives or dies to itself, that the consequences of every move are not only direct but far-reaching till the game is done.

The Story of the Gullery

From one we may learn all, so we take from Dr. Ritchie's book a single instance of the intricate interlinking of lives. It concerns a colony of black-headed gulls (*Larus ridibundus*), which established itself on the White Moss, near West Linton, in Peeblesshire. In 1890 the Moss was a typical heather moor, with peat and moisture underneath. In 1892 or 1893 a few pairs of gulls came to nest on the Moss, and were encouraged; in 1897 there was a populous colony; in 1904 the number was estimated at 1,500 to 2,000 pairs. The vegetation round about the colony underwent a remarkable change; the heather was replaced by coarse grass, and that by rushes, and these by a forest of docks. These changes in the flora were due, of course, to the faunistic gull-invasion. The poor soil, which only the symbiotic heather could make anything of, was fertilised by food-refuse and excreta from the gullery. Moreover, the puddling of the surface ground by the thousands of busy webbed feet, and the surface accumulation of crowded nests, meant a retention of superficial water. At all events, the peat bed with its concealed and deep moisture was transformed into a surface marsh.

But further changes were in progress. The grouse that used to frequent the moor took their departure. Teal ducks arrived on the scene, attracted by the marsh and the rushes. A single flock, when the gullery was at its height, numbered seventy. The grouse were out, the gulls and teals were in.

Fifteen years passed, and the scene was changed. Man interfered again, for he rapidly ousted the gulls from their tenancy of the White Moss. The villagers were disappointed because the coarse grass they had been wont to cut had been replaced by useless docks. The proprietor, who had been using a proportion of the gulls' eggs as food for his young pheasants, was disappointed because the grouse had gone. So the edict went forth against the gulls. In the early summer of 1917 scarcely a gull was to be seen; the docks had almost disappeared; the rushes were giving way to rough grasses and even heather; the teal had gone and the grouse were returning. In a few years a slight imprint of man's hand had set in motion a complicated cycle of changes. The story is like a Darwinian diagram, and Darwin might have written the sentence with which the story ends:

> If the natural processes set a-rolling by a tiny and temporary interference of man can be so marked, how can imagination grasp the total effects of man's influence, impressed upon the world of Nature often with great power, and persisted in, not for a few years, nor for a few centuries, but for thousands, nay, even for tens of thousands of years.

The practical moral of this and every other story of inter-relations is that man should be very careful in his interferences with the system to which he belongs.

§ 5

The Weird Ways of Parasites

When one organism lives in or on another (its "host"), gets its food from it, has its life-history inextricably bound up with it

and is not beneficial but rather injurious in its influence, we speak of parasitism. But a clear-cut definition is impossible; many parasites do very little harm to their hosts unless these get out of condition; many parasites are unimportant unless they get into some vulnerable part of the body; many external parasites clean up their host's skin. A parasite may become a symbion, as has probably occurred in the case of the heather-fungus. There are many degrees of parasitism, from external hangers-on like fleas and lice to internal boarders like tapeworms and threadworms. There is also an important distinction between parasites that live in the food-canal of a host, sharing in the digested food, as tapeworms do, and those that prey upon the living tissues like the liver-fluke, which feeds on the blood of the sheep's liver. It is not in the interest of parasites to kill their host; that is lopping off the branch on which they are seated. Perhaps the trypanosome which causes sleeping-sickness in man is not so much a parasite as a predacious Infusorian devouring man from within as a lion might do from without. A very important consideration is that a parasite often establishes a live-and-let-live compromise with its host, and nothing remarkable happens unless the parasite is transferred to a new host which is not in any way accustomed to such an intruder. Thus transference to man is, as it were, an accidental episode in the life-cycle of the trypanosome of sleeping-sickness—not that the life-cycle is as yet clear.

It is important to see parasitism in its proper perspective: it is a way of evading part of the struggle for existence. Just as some animals have discovered caves, others have discovered hosts. The discovery usually means abundant food and safe shelter; it often involves a very riskful life-history. It is an interesting fact that in some types, e.g., among crustaceans and insects, only the females are parasites, which suggests that the habit sometimes arose in connection with egg-laying and the protection of the offspring.

Photo: W. E. Berridge.

CORMORANTS

Cormorants are greedy fish-eaters, but it must be remembered that they feed on many fishes, such as eels, which devour the fry of useful food-fishes. They also keep a check on some other fry-eating animals, such as crabs. The intricacy of the web of life is such that it is occasionally difficult to get a clear issue for or against a bird, as far as man's interests are concerned. There is often something to be said on both sides. In China and Japan tame cormorants are used by fishermen, a leather collar being placed round the neck to prevent them swallowing what they seize. The cormorant usually nests on the ledges of cliffs. When feeding its young, the mother takes a great part of the chick's head into its mouth.

Photos: J. J. Ward.

A PAIR OF LADY-BIRD BEETLES FEEDING ON APHIDES OR GREEN-FLY

These beautiful little beetles play a very important part in checking the multiplication of plant pests. They are very voracious, singularly free from enemies, and very prolific. The leaf shows some of the "moults of the Aphides."

SUMMER GREEN-FLY MULTIPLYING ON THE FLOWER OF THE SWEET-PEA

All through the summer the young are produced viviparously from eggs which do not require fertilisation (parthenogenesis). The young soon become mature and bring forth another generation. There are no males till near the end of the season.

Photo: J. J. Ward.

HEDGEHOG DRINKING

The inter-relations of the Hedgehog are many, for it has a large range of appetite. It often eats insects and their larvæ slugs, small snails, and earthworms. But it occasionally devours a frog, an egg, a nestling, or a newborn leveret. It fights with the adder, but it seems to be immune to the venom. It plays a very useful part in the economy of Nature.

Photo: F. R. Hinkins & Son.

A BRACKET FUNGUS GROWING AS A PARASITE ON A BIRCH-TREE

Fine threads penetrate into the tissue of the tree and absorb nutritive material. Much damage is often done to the tree.

Adaptations of Parasites

Evolution is not always progressive, and it is illustrated in the adaptations of parasites as well as in the adaptations of birds. Parasites tend to go back, but their very retrogressions may be effectively adaptive to the conditions of their inglorious life of ease. Let us take the case of a tapeworm, floating in the human intestine amid the half-digested food, and moored by its head to the wall.

> It is safe from all enemies (unless, perhaps, the medical practitioner with his vermifuge); it floats in a plethora of food, which it can absorb by the whole surface of its long tape-like body; it can live and thrive with a minimum of oxygen, and it has a mysterious "anti-body" which preserves it from being digested by its host; it has on its head muscular adhesive suckers, and, in some species, attaching hooks as well, so that it is firmly anchored to the wall of the intestine; it sojourns in warmth and comfort without any expensive sense-organs to keep up; with its low type of nervous system it lives a life of dull sentience. It has attained to what economists have called complete material well-being.[1]

But there is the seamy side of the tapeworm's "life of ease" —namely, degeneracy. There are no sense-organs; the nervous system is of a very low order, without any brain; the muscular system consists of smooth muscle-cells which contract sluggishly; there is no mouth or food-canal. The reproductive system is complex, but there is a suggestion of degeneracy in the frequent occurrence of self-fertilisation—a very rare thing among animals. Some tapeworms produce eight million eggs, and prolific multiplication is certainly common among internal parasites. There are two ways of looking at this. Abundant and stimulating food, such as parasites often command, tends to make the individual prolific. This is the individual and physiological aspect. But the continuance of the race is often very diffi-

[1] Thomson, *The Wonder of Life*, 1914, p. 301.

cult in the case of a parasite that requires two hosts, as so many do, and we may conclude that those types which were constitutionally capable of prolific reproduction would be the successful survivors. It cannot be doubted that many animals enter the door of parasitism, but fail to leave it open for their progeny. So they die out in their asylum. The astonishing thing is that so many have succeeded. The dog is known to have about forty different kinds of parasites; both man and the pig have more. In omnivorous types the alimentary parasites are always more numerous than in those with a specialised diet. Some constitutions seem to favour or attract parasites; thus the European oak-trees harbour about a hundred different kinds of gall-flies.

It is not only the number of different kinds of parasites in one host that amazes us, it is also the numerical strength of one kind. Thus there may be 10,000 individuals of one kind of threadworm in the intestine of one grouse, the minute larvæ being swallowed along with the leaves and flowers of the heather.

Another interesting point is that particular kinds of parasites are usually restricted to one kind of host, one reason being that they cannot be adapted to a variety of surroundings. When the parasite requires two kinds of hosts for the completion of its life-cycle, the host of the adult is in many cases an animal that habitually eats the host of the larval stage. Thus the dog eats the rabbit, and the bladder-worm of the rabbit develops into a tapeworm of the dog. Similarly, the bladder-worm of the mouse becomes the tapeworm of the cat. Man gets his two commonest tapeworms (*Tænia saginata* and *Tænia solium*) by eating imperfectly cooked flesh of ox and pig respectively, for these are the hosts of the bladder-worm stages.

The larva of the liver-fluke cannot continue its development in Britain unless it gets into a particular species of freshwater snail, called *Lymnæus truncatulus* or *minutus;* if it enters another species it is unsuccessful. This is what we mean by specificity or individuality of life-history. And yet the same liver-fluke larva

in some other countries is able to utilise another species of water-snail. When we examine the food-canal of a mammal, bird, or fish that has not previously been studied in this connection we often find a new tapeworm or threadworm. We wonder how far this illustrates the rôle of isolation in assisting the formation of new species. Just as there is an Orkney Vole and a St. Kilda Wren, and a distinct species of land-snail in each of the sharply isolated valleys in Hawaii, so there are different species of tapeworms, flukes, and threadworms in diverse hosts. We wonder whether the apparently different species of parasites may not be to some extent the same species, slightly modified by the differences in surroundings and food! Here there is opportunity for important experiment.

What is it exactly that parasites do to their hosts? Some absorb a good deal of digested food from the intestines; some perforate the wall of the food-canal; some cause inflammation by vitiating the surrounding tissues; some block passages, even blood-vessels; the mite of so-called Isle of Wight bee-disease blocks certain air-tubes and cuts off air from the muscles, besides feeding on the bees' blood; the sturdieworm of the sheep presses upon the brain or the spinal cord, causing serious locomotor derangements; some tapeworms and threadworms secrete a toxin; some peculiar crustacean parasites, e.g., Sacculina, destroy the reproductive organs of male crabs. In short, the influence of parasites is very manifold.

§ 6

The Romance of Parasitism

There is something repugnant in most parasites; we cannot look at them without some ethical recoil. We know that they are creatures which do not fend for themselves. Moreover, many of them are far from beautiful, which may be to some extent the stigma of their degeneracy. A sluggish pampered animal is not

likely to have pleasant lines. The mistletoe is pretty enough, but as it is only a half-parasite it may be one of those exceptions that prove the rule. Our recoil is also in part due to a recognition of the menace that many parasites involve. The hookworm and the guinea-worm are curses. All the same there is an astounding, undeniably romantic element in the life-histories of many parasites. Let us take the liver-fluke as an instance.

The adult liver-fluke (*Distomum hepaticum*) lies like a flat leaf in the tributaries of the bile-duct of the sheep and some other mammals. It is about an inch long. It sucks in the blood of the liver, and it causes the disease expressively called liver-rot. Like most internal parasites, it is very prolific, each being capable of producing 50,000 eggs, which are fertilised by sperms from the same animal—a rare state of affairs called autogamy. The developing enshelled eggs pass down the bile-duct, down the intestine and on to the ground. If they land on a dry place, such as a pathway, they soon die; if they come to rest in a damp place, e.g., among wet grass, they continue developing for a time. But they will not come to anything unless they reach a pool of water. Thus drainage of pasture-land has greatly reduced the amount of liver-rot.

In the pool of water a microscopic, pear-shaped, ciliated larva escapes from the egg-shell and swims about actively. It has two minute eye-spots, but no mouth or means of feeding. So it cannot continue swimming for more than a limited period, about eight hours.

During its swimming it comes near or in contact with many things, such as stick and stone, water-weeds, and small animals, but it answers back to nothing, save the touch of the little water-snail (*Lymnæus truncatulus*), which is very common in pools. When the larval liver-fluke touches the mollusc it immediately enters, finding the breathing aperture a convenient doorway. We do not understand the specific irritability of the tiny brainless

Photo: F. R. Hinkins & Son.

HAZEL STEMS STRANGLED BY HONEYSUCKLE

The Hazel stem grows thicker in the parts not encircled by the honeysuckle and so assumes this twisted appearance. The inter-relation here is not one of parasitism in any way. The honeysuckle is simply using the hazel as a support by which it can raise itself to the light and the free air. In the Tropics, giant trees are killed by the similar action of the lianes, which are a very characteristic feature of the forest vegetation.

Photo: J. J. Ward.

THE LIVER-FLUKE—THE CAUSE OF "LIVER-ROT" IN SHEEP
(Magnified about 4 times.)

This leaf-like or trowel-like flat worm, technically called *Fasciola* or *Distomum hepaticum*, is about an inch long by half an inch across at its broadest. It has the thickness of stout brown paper. It varies a little in colour, e.g. reddish-brown or greyish-yellow. The adult is found in the liver of the sheep (occasionally in cattle, deer, horses, and other mammals), and it feeds on the blood. The juvenile stages are passed in the small freshwater snail—*Limnæa truncatula*—a good instance of the interlinking of lives.

Photo: J. J. Ward.

A BUNCH OF ZOOPHYTE GROWING ON THE SHELL OF A HORSE-MUSSEL

Superficially the zoophyte looks a little like seaweed; but closer examination shows it to be a great colony of minute tubular animals or polyps. In this case the association is quite external. The zoophyte is "epizoic" on the mussel, just as moss may be "epiphytic" on a tree.

Reproduced from Fabre's "The Wonders of Instinct."

THE BLUEBOTTLE LAYING HER EGGS IN THE SLIT OF A DEAD BIRD'S BEAK

larva which leads it to respond to the touch of the only creature which will allow of a continuance of its life-history. It is a racially enregistered responsiveness, but these are only words hiding our lack of understanding. If there is no water-snail in the pool, or if the larva does not find it during the eight hours' limit of its free swimming, it will come to nought.

Inside the water-snail the larva loses its cilia and eye-spots, and becomes a sporocyst; this gives rise by means of spore-cells (germ-cells requiring no fertilisation) to 5-8 larvæ of another type called rediæ. These give rise in the same way to 8-12 more rediæ, and these to 12-20 larvæ of a third type called cercariæ. These are the young flukes at last, with a bilobed food-canal, the beginnings of suckers and reproductive organs, and a locomotor tail. If a water-wagtail were to swallow the infected water-snail at this stage, that would be an end of the parasites as well. This is another chance against success.

From the moribund snail the tailed larvæ wriggle out; they swim in the water, they swarm up blades of grass, they encyst as tiny white spots, losing their tail in the process. If the sun wither the grass the whole story is at an end. The only event that will secure continuance is that a sheep eat the blade of grass bearing the tiny encysted larva. From the food-canal of the sheep the cercaria migrates up the bile-duct to the liver, and in a few weeks becomes mature. In some cases the full-grown flukes die in the sheep's liver after reproduction; in other cases they migrate out of the liver, down the food-canal, and die on the ground. The most important general fact is that the life-history of the liver-fluke shows a succession of risks of complete failure. Had it not been for their prolific multiplication, liver-flukes would have passed off the stage long ago.

Pearls and Parasites

It sometimes happens that an irritant body, such as a grain of sand, gets in between the shell of a pearl-oyster (or a fresh-

water mussel) and the underlying skin or mantle, which lines the shell and is always adding to it (see colour plate facing p. 650). Round the intrusion the skin secretes layer after layer of mother-of-pearl, or nacre, and a sort of pearl is formed. But this is not a true pearl. It is usually adherent to the shell and has a solid foreign body, sometimes opaque, at its core.

A finer result is obtained when a tiny hole is bored in the shell and a rounded granule of mother-of-pearl is slipped in between the shell and the skin. The hole is sealed up and the "pearl" is left to grow. In this case the result is more homogeneous, for the core is of mother-of-pearl. But this never yields what is called a "fine pearl."

An improvement on the previous procedure consisted in introducing into the skin of mussels little fragments of living tissue. In the course of time these were found encased in concentric layers of mother-of-pearl, yielding reputable pearls. It is probable that this method is capable of great improvement.

What happens in natural conditions is rather different. In the common edible mussel a pearl may be formed from a sac of skin-cells surrounding an intruding fluke-larva. The skin-cells secrete a sepulchre for the fluke—delicate concentric layers of mother-of-pearl. As the core is the tenuous remains of a very delicate and minute parasite, the pearl that results has considerable opalescence. Similarly, some naturalists believe that the fine pearls of the Oriental pearl-oyster are formed round intruding larvæ of a tapeworm, but conclusive proof is wanting.

There is considerable reason for believing that pearls often arise round nuclei of the substance called conchin, which is secreted by the skin as the organic foundation of the calcareous shell. A little blob of this clear secretion, formed in a skin-sac as the result of some slight disturbance in the ordinary routine of shell-making, may form the centre of a really fine pearl, which is built up of numerous concentric layers of nacre.

Theoretical Aspects

In connection with evolution it is often asked how Natural Selection, i.e., Nature's sifting and singling, can be expected to act on the little finicking details which are so characteristic of living creatures. To this very reasonable question Darwin himself gave the answer by the emphasis he laid on the web of life. For in the gradually evolved and ever complexified system of inter-relations there is a sieve of extraordinary delicacy, which will discriminate between even minute fluctuations to the plus or the minus side. An apparently trivial new departure is tested in reference to the established system of inter-relations. A shibboleth may decide the fate of a species.

Another question often raised is as to the general progressiveness of evolution. There have been retrogressions, blind alleys, lost races, but on the whole life has been slowly creeping upwards through the ages. But why should it? This is a difficult question. But may not part of the answer be found in the gradual complexifying of the web of life? There is established an external system of inter-relations which is always becoming more intricate—take the linkages between flowers and their insect visitors in illustration—and this forms the sieve by which variations are sifted. In the progress of mankind there is an external registration of racial gains; there is throughout Nature just the beginning of this—an external systematisation of inter-relations which we call the web of life.

Finally, it is important to acquire as a habit of mind the vision of the web of life. It is distinctively the scientific way of looking at things, to appreciate their inter-relations, to see Nature (and human life as well) as a vibrating system most surely and subtly interconnected. But in addition to the influence on our theoretical outlook, there is the practical importance of the idea of inter-relations. If we are to persist and advance in civilisation, we must pay more heed to the web of life, to all the strange junctions in our lines of communications. We cannot play the game

without observing the rules, and these include a recognition of the web of life. We are part of a system, in which it is not the first or the second consequence of a move that counts, but the sum of consequences.

BIBLIOGRAPHY

Beneden, *Animal Parasites and Messmates* (International Science Series, 1876).

Darwin, *The Origin of Species* (1859) and *The Formation of Vegetable Mould through the Agency of Worms* (1881).

Dendy, *Animal Life and Human Progress* (1919).

Gaye, *The Great World's Farm* (1893).

Geddes, *Chapters in Modern Botany* (1893).

Keeble, *Plant-Animals* (1910).

Kerner, *Natural History of Plants.*

Lankester, *The Kingdom of Man* (1907).

Mill, *The Realm of Nature* (1892).

Müller, *Fertilisation of Flowers by Insects* (1883).

Newbigin, *Man and his Conquest of Nature* (1912).

Ritchie, *The Influence of Man on Animal Life in Scotland* (1920).

Semper, *Animal Life* (1881).

Shelford, *Animal Communities* (1914).

Skene, *Common Plants* (1921).

Thomson, "Man and the Web of Life," in Dendy's *Animal Life and Human Progress* (1919).

Thomson, *The Wonder of Life* (1914).

Thomson, Margaret, *Threads in the Web of Life* (1910).

White, *Natural History of Selborne* (1788).

XIX

BIOLOGY

By Julian S. Huxley, M.A.

BIOLOGY

THE NATURE OF LIFE—REPRODUCTION—REGENERATION—THE DUCTLESS GLANDS

By Julian S. Huxley, M.A.

Matter, Living and Lifeless

FROM the earliest times human beings have pondered over the nature of life. At the beginning they tended to think of all things in terms of themselves—to read a life into the wind, a spirit into the river, a soul like their own into the birds and beasts, nor did man even hesitate, as Voltaire so succinctly put it, "to construct God in his own image." But this projection of oneself into the objects of the world around, or anthropomorphism, as it is generally called, is, from any scientific or rational point of view, one of the cardinal vices of the mind. To discover the real nature of things, we must discard all prejudices, all purely instinctive ways of thinking, and labour along the stony but sure path of reason and verification.

At the outset, it seemed self-evident to anthropomorphism that all living things were alive because endued with some vital principle, some spirit of life, which departed from them at death. But all recent work is making it ever more probable that there is no such specific vital force, and that life is but one name for the manifestations of particular types of matter of very complicated construction.

By putting a man or an animal into a special chamber, fitted up as a calorimeter, we can measure the amount of energy produced by him in the form of work and of heat; and we find that,

within the ordinary limits of experiment, it is identical with the amount of energy which would have been produced in the form of heat, if the food supplied to him had been burnt. The principle of the conservation of energy thus holds good for a dog or a man as well as for a steam-engine or a dynamo; no special "vital energy" is being mysteriously introduced.

It is the same with the chemical composition of living organisms. There are no elements in our bodies which do not exist in lifeless matter; and, indeed, the chemical constituents of living matter are all to be reckoned among the commoner elements. The bulk of living substance is composed of four ubiquitous elements—carbon, hydrogen, nitrogen, and oxygen; besides these, iron, phosphorus, sulphur, sodium, potassium, calcium, chlorine, and probably iodine seem to be universally present.

It was at one time supposed that a distinction between living and non-living matter could be drawn in respect of their powers of chemical construction. Many chemical substances, such as starch, sugar, albumen, urea, and so forth, are only to be found normally as the product of living organisms; and it was supposed that the "vital force" concerned itself with the manufacture of such special compounds. This again, however, has proved not to be founded in fact. In the middle of last century, Wôhler succeeded in synthesising urea out of lifeless matter in a test-tube. Since that day more and more organic substances have been artificially made.

The most complicated chemical substances which have been isolated from living matter are the proteins (such as the albumen of egg white), consisting, as they do, of hundreds, often thousands, of atoms; these are combined first of all into comparatively simple compounds, called amino-acids, and the amino-acids in their turn are linked together in definite ways to form the hundreds and thousands of different proteins that we know.

Emil Fischer has succeeded in artificially linking together a number of amino-acids to form a very complicated synthetic

compound; and there can be little doubt that it is only a question of time until synthetic proteins can be made out of lifeless material in the laboratory.

There is thus no measurable scientific criterion by which we can distinguish living from lifeless matter. The kinds of matter are the same; the ways they work—their energy transformations —are the same; it is only their arrangement that is different. Living matter is a particular and very elaborate arrangement of ordinary matter. If this at first sight seems startling, we may remind ourselves that it is only the arrangement of the same twenty-six letters that distinguishes, say, Hamlet's soliloquy, or Keats' Ode to a Nightingale, from a page of advertisements or a Limerick.

Of the origin of life we have, in the nature of things, as yet no definite knowledge; but everything points towards this conclusion—that during the gradual cooling down of this planet a state of affairs arose which inevitably led to the production, in that cosmic laboratory, of molecules which were alive in that they had the power of reproducing themselves and reacting to stimuli, and gave rise to the living things that we see to-day; in other words, that there has not only been an evolution of all living things from one common ancestor, but of all life from not-life.

§ 1

Can Mind Arise from Lifeless Matter?

But, it will be immediately objected, what about mind? Man and the higher animals possess mind: can we suppose that that too has arisen from lifeless matter? It may very well be that we can—if we somewhat enlarge our ordinary view of the nature of matter. It is now a commonplace of psychology that self-consciousness is not the only, but simply the highest, development of mind. Below it are various grades of mental being, leading through the types of consciousness that young children seem to

possess down to and beyond the sub-conscious types of mind that hypnotism and psycho-analysis reveal. We have only to be completely logical and believe that something of the same general nature as mind exists in all life, to make the further step, and believe that it exists, even in the matter from which life sprang. In that case, as G. H. Parker has well said, we would have to enlarge our definition of matter, for the properties of "matter," that is to say, of the world-stuff, would include mind.

Perhaps an analogy will make the argument clearer. We know that every time a muscle contracts a slight electrical discharge is produced. The same is true of a gland each time it secretes; and probably no process of life is possible without some minute accompanying electrical charge. But these electrical charges are only just measurable, and in the vast majority of organisms are of no use whatever to their possessors. In the electric eel, however, and one or two other fish, certain muscles of the body have been modified to form electrical organs, in which the small electrical charges are added to each other, so that their cumulative effect is a serious shock. Electrical change, that is to say, occurs in all organisms inevitably, because of the way they are made; but in these few animals special organs have been evolved for intensifying electrical change, and so making it of use to its possessor. In the same way, if we think of the processes of matter as always involving some rudimentary, infinitesimal change of the general kind we call mental, it appears that, in the course of evolution, organs (which we call brains) have been evolved for intensifying these changes, and so giving rise to mental activity of direct use to its possessors.

Theories of the Origin of Life

There have been other theories of the origin of life on this planet—for instance, that its germs were transported here on meteorites from other stars; but this only removes the problem of life's origin one step back, and does not solve it.

Photo: Rischgitz Collection.

LOUIS PASTEUR

The great French scientist who passed from work on chemistry to researches on the origin of life, and from these to pioneer experiments in the fields of bacteriology and immunity.

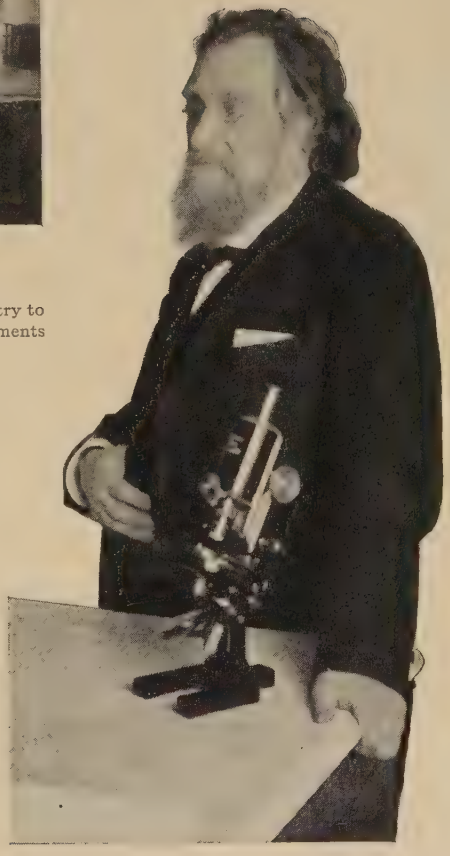


Photo: Henri Manuel.

METCHNIKOFF

The Russian scientist who took up Pasteur's work at the Pasteur Institute in Paris. Perhaps his greatest claim to fame consists in his discoveries concerning the devouring of foreign particles by the white corpuscles in the blood.

Photo: J. J. Ward.

A SPOT OF POND WATER AS IT APPEARS UNDER THE MICROSCOPE, SHOWING VARIOUS FORMS OF UNICELLULAR PLANTS, ETC.

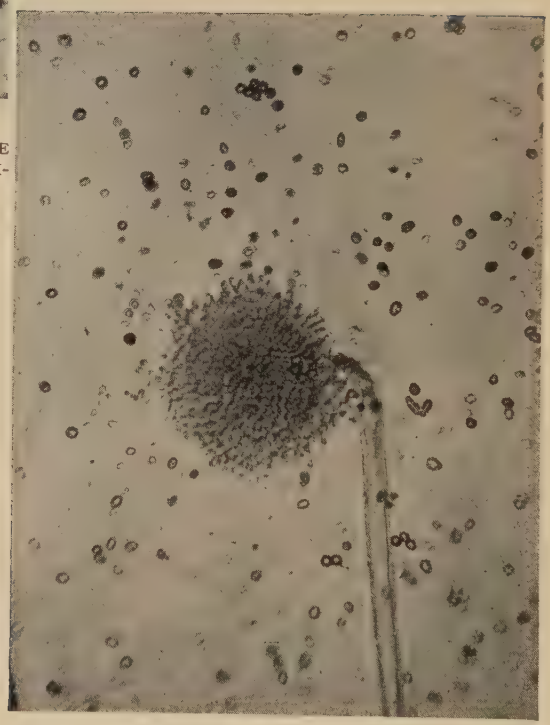


Photo: J. J. Ward.

BLUE CHEESE MOULD

The spore head of Blue Cheese Mould is shown bursting and scattering its spores, which float in the air and fall on food material and develop new mould plants.

At the present day, when the conditions must be very different from those which could have existed when life was first evolved, there does not seem to be any spontaneous transformation of lifeless into living matter. This has only been proved in quite recent years; the doctrine of spontaneous generation has been held by all primitive peoples, and maintained itself even among scientific men, until the middle of last century. The popular belief that a dead carcase would breed bees is to be found in the Bible and in Virgil. Country-folk believe to this day that a horsehair put into a pond will become transformed into an eel; and it was only in the eighteenth century that Redi disproved the popular supposition that maggots were "bred" from decaying meat, by showing that none appeared when the meat was screened, and when the flies could not, therefore, lay their eggs on it.

The discovery of the microscope, however, and its revelation of the teeming, hitherto invisible world of protozoa, unicellular plants, moulds, and bacteria, altered the position; and it was believed almost universally that these low forms of life were generated spontaneously in the processes of decay. It was Pasteur, the great French scientist, who, together with Tyndall and others finally gave the theory of spontaneous generation its death-blow. By a series of ingenious experiments, he showed that liquids, which in ordinary circumstances would become a mass of bacteria in a day or so, remained free from all living organisms if thoroughly boiled. This was true even if fresh air was admitted to them, provided that it was filtered through cotton-wool, or in some way first made to deposit any solid particles it contained. In fact, he showed conclusively that whenever life appeared "spontaneously" in a culture-fluid, it had always really been transported there through the air in the form of invisible "germs," and thus, without realising it, he laid the foundations of the whole science and practice of bacteriology. Nowhere is there to be found a better example of vastly important practical results accruing from the simple pursuit of knowledge for knowledge's own sake.

It is safe to say that every organism living to-day has descended from a pre-existing organism; the chain of life has been unbroken since before the first records of geological history millions and millions of years ago.

§ 2

Protoplasm and the Construction of the Body

Protoplasm, as a great nineteenth-century biologist said, is "the physical basis of life." It is the living part of all organisms, whether animals or plants, as distinguished from such non-living substances as hair, or the hard parts of bone, or accumulations of fat or starch, all of which are products of its activity. Under the microscope it is seen to be a semi-liquid substance, somewhat granular, almost colourless, apparently simple, but really, as we know, of the utmost chemical complexity. Some of the lowest forms of life, like the Amœba, are naked and undifferentiated bits of this living matter. But even in their unspecialised protoplasm we find the rudiments of all the properties to be found in the highest animals and the most delicate organs. In the first place, it has the power of assimilation; it can build up dead matter into its living molecules and transform foreign material into substance like its own.

Then it is sensitive to stimuli—mechanical shock will cause it to contract, strong light or heat will damage it, certain chemicals will attract or repel it, electric currents will force it to move in a particular direction. It is out of these primitive properties that all our complex sense-organs have been built up. Because light will alter the protoplasm of an Amœba, it has been possible for life to evolve an eye. And, be it remembered, the reverse is true. Hertzian or wireless waves are so large that they do not affect simple protoplasm; and no sense-organ has been evolved for their perception.

The Amœba uses up oxygen and gives out carbonic acid gas; it can move; it grows; it reproduces. Such are the fundamental

properties of all protoplasm, and on these evolution has reared its great edifice and brought into being that almost incredible multiplicity of species (nearly a million are known already) of animals and plants, ranging from a whale to a flea, an oak to a toadstool, a tapeworm to a bird, a bacterium to a lily, a jelly-fish to an ant-community, a worm to a philosopher.

§ 3

The Units of Life

We have already seen that apparently homogeneous bits of matter—a half-crown, or a tumbler-full of water, or a grain of salt—are all composed of minute material units, or molecules. In a similar way, the bodies of living things are built up out of units. If we dissect the body of a human being or an animal, we find that it is formed of a number of organs such as the heart, the stomach, the brain, the hand, each with some particular type of work to do for the benefit of the whole organism. Every organ in its turn is composed of a number of tissues, each of which *seems* to be homogeneous. The stomach, for instance, is formed of secreting tissue inside, muscular tissue outside, and it is supported and bound together by connective tissue, and is penetrated throughout by blood-tissue in the blood-vessels and nervous tissue in the nerves.

But when we come to examine these tissues under a good microscope, we find that they are not homogeneous at all, but composed of a number of separate units called cells. In the blood these cells are separate and independent, while in other tissues they are united with each other.

Many people still find it difficult to believe that man is descended from Simian ancestors, these in their turn from lower mammals, and so from ever simpler and simpler progenitors. They can never have grasped the plain fact of observation, that the body of every man and woman alive has grown from a minute undifferentiated cell.

Every higher animal starts life as a single cell, the fertilized ovum in the case of man; this measures no more than $\frac{1}{125}$ of an inch in diameter. The processes of development can all be thought of in terms of cells, their multiplication, their migration, and their changes of form.

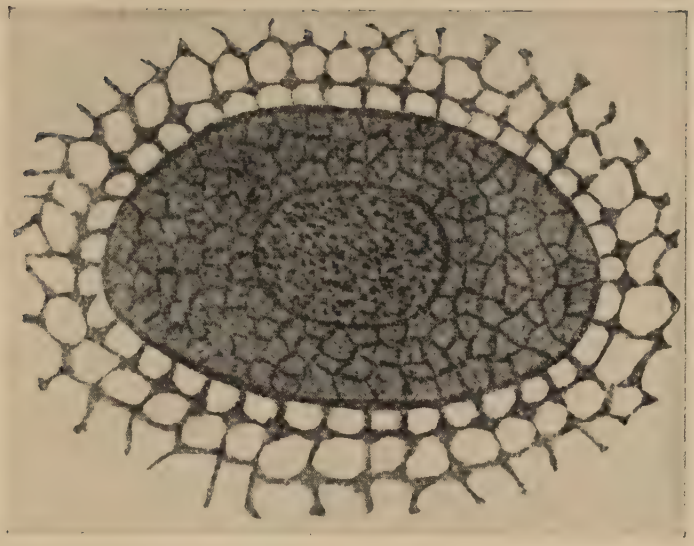
The first stages in development consist in the cutting up of the ovum into a number of similar or almost similar rounded cells. In the next stage, the rough ground plan of the future embryo is blocked out by the formation of the three layers of cells to be found in all higher animals.

During the succeeding stage, a more detailed plan is substituted for the rough sketch, and the main organ-systems are laid down. The outer of the three layers gives rise to the future brain and spinal cord, the eye, ear, and nose, the outer skin; the innermost layer modifies itself into a sketch of the gut, with liver, sweetbread, thyroid and other glands; while the intermediate layer produces the rudiments of the blood-system, the kidneys, the muscles, and the skeleton. With the intermediate layer are also associated the reproductive cells, but they, as we have seen, stand somewhat apart from the ordinary tissues of the body.

We have spoken of the laying-down of a plan. That and no more is what development has up to this stage produced; the rudiments of the future organs are distinguishable, they are in their proper places, but they do not yet *work;* and they do not work because the cells of which they are composed are still all nearly alike and not yet specialised to perform different duties.

It is only in the succeeding stage, the stage of tissue-differentiation, that the various types of cell lose their original rounded or cubical forms, and begin assuming the appearance which they will have in the developed organism.

Some of the chief types of cell-change that occur may be briefly mentioned.



PROTOPLASM OF NUCLEUS WITH PART OF SURROUNDING PROTOPLASM, FROM GANGLION CELL OF AN OX. (From Bütschli.)

Photo: J. J. Ward.

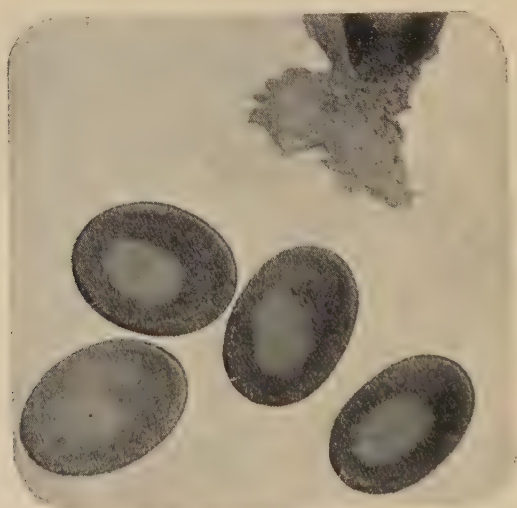
SECTION OF THE HEART OF A PINE BUD

Showing the growing point where the cells are dividing to form other cells which become modified and specialised to carry on the various functions of the plant.

From "*The Problem of Age, Growth, and Death*," by Charles S. Minot (*John Murray*).

DIFFERENTIATION OF CELLS IN THE LENS OF A CHICK'S EYE

1. A section at 68 hours; 2. at 96 hours; some of the cells (at *B*) are becoming elongated and transparent. *C*. The cavity of the lens, which gradually becomes obliterated.



From "*The Essentials of Histology*," by Sir Edward Sharpey Schafer (*Longmans, Green & Co.*).

FOUR RED BLOOD CORPUSCLES AND A WHITE CORPUSCLE OF A FROG; THE LATTER HAS ENGULFED A WORN-OUT RED BLOOD CORPUSCLE

Magnified 600 diameters.

The Blood-cells

The blood-cells are of two sorts. One is active and resembles an Amœba in its capacity for changing its shape and swallowing foreign particles: these are the white corpuscles or phagocytes. On the other hand, the red corpuscles (from which blood derives its colour, the liquid part or plasma being colourless) are mere disks charged with hæmoglobin, the pigment which by its affinity for oxygen and carbonic acid gas is the vehicle of respiration.

These red corpuscles are produced in the marrow of the long bones, and are continually being budded off there, to be destroyed in the spleen when worn out.

When a smooth lining to a cavity is required, as in the abdominal cavity round the intestine, the cells bordering it become flattened and pieced together like the bits of a jig-saw puzzle. When, on the other hand, cells are destined to manufacture and pour out chemical substances—in other words, to become part of a gland—they are elongated vertically, and drops of secretion can be seen within them.

The tissues where reserve food is to be stored up in the form of fat are made up of cells stretched like a tight skin over the fat-droplet which they contain. When hard supporting tissue is to be formed, as in the skeleton, it too is produced by the activity of cells. In gristle or cartilage, for instance, the rounded cells form layer after layer of glassy gelatinous material round themselves; whilst in the bone the cells are branched and arranged regularly, and the material they lay down round themselves is hardened with lime-salts. In the same way, the connective tissue which binds all the organs of the body together is made chiefly of microscopic fibres, some tough and resistant, some elastic; but these are all formed by the cells lying scattered between them.

The meat we eat is mainly muscle; a muscle, too, is made of cells. In smooth muscle, as in the bladder, the cells are very long with faint longitudinal lines; but in the more efficient striped

muscle of our limbs, which is under the direct control of the will, the cells are enormous, with many nuclei, and the microscope shows that the substance of the cells is cross-striated. The alternation of dark and light bands which gives this appearance is, in some way as yet unknown, necessary for rapid contraction, and it is best developed in such muscles as those of insects' wings, which vibrate with almost inconceivable rapidity.

The cells of the outer skin, or epidermis, have a singular fate—they are continually being sacrificed for the good of the body as a whole. The lower layers of the epidermis consist of rounded cells which are rapidly multiplying; as the cells thus produced approach the surface they become flattened and, finally, converted into horny material, which eventually flakes off as the so-called scarf-skin. The continual shedding of this usually passes unheeded, but becomes at once evident by the masses of it which accumulate when a bandage is left on for long. By this means the skin continually renews itself, and the soiled and bruised outer layers are shed and replaced by new cells from below. A similar conversion of cells from horny material takes place in our nails and hair; but here the horny structures are relatively permanent.

The Brain-Cells

The brain too, the organ of mind itself, is composed of cells. The cells of the brain and spinal cord undergo, perhaps, the most remarkable development of all. Originally, in the embryo, they are of simple and rounded form and like other cells; they develop outgrowths, usually two in number, which often grow to great lengths and may branch repeatedly. Of the finest terminal branches, some come into contact with the cells of muscles and glands, others with the cells of sense-organs like the eye and ear or the touch-spots in the skin, others with similar outgrowths of other nerve-cells. In this way every organ in the body is linked up with every other, through the mediation of a living telephone

system formed by chains of nerve-cells and their outgrowths. The usual motor nerve-cell (i.e., a nerve-cell concerned in sending messages to muscles and glands) has a short outgrowth within the spinal cord, whose branches connect with the branches of several other nerve-cells of different sorts, but the characteristic feature is a very long nerve-fibre leading to the muscle concerned. This, in the case of the nerve supplying the muscle of the foot, may be several feet in length.

The most extraordinary cells in the body are probably those in the fore-brain, or main part of the fore-brain, in the layer which is the seat of the process of thought. The figure (facing page 684) will show the immense complexity of their interlacing branches—a complexity which presumably makes possible the amazing process which we call the association of ideas.

Finally, the act of reproduction itself is carried out by special cells which are formed in the reproduction organs and set free when mature. In early stages, both types of reproductive cells have the same rounded form and large nucleus. But, while the female cell or ovum remains rounded, and increases enormously in size by the accumulation within itself of yolk-grains as reserve food material, the male cells remain small and finally become transformed into spermatozoa. The nucleus condenses and elongates to form the so-called head, and the rest of the cell is pulled out to form a long, actively vibrating tail, by means of which the sperm propels itself and eventually, it may be, reaches the ovum.

§ 4

The Body a Huge Cell-State

Cells are for the most part quite microscopic in size. Human red blood corpuscles, for instance, are so tiny that, in the volume of blood equal to a cube one millimetre each way (about $\frac{1}{15000}$ of a cubic inch), some five millions of them are floating—roughly the population of London. As the amount of blood in an average man amounts to about 7 lbs. by weight, this figure must be

multiplied about three million times to give the total number of red corpuscles in the body; a similar figure would be found for other sorts of cells.

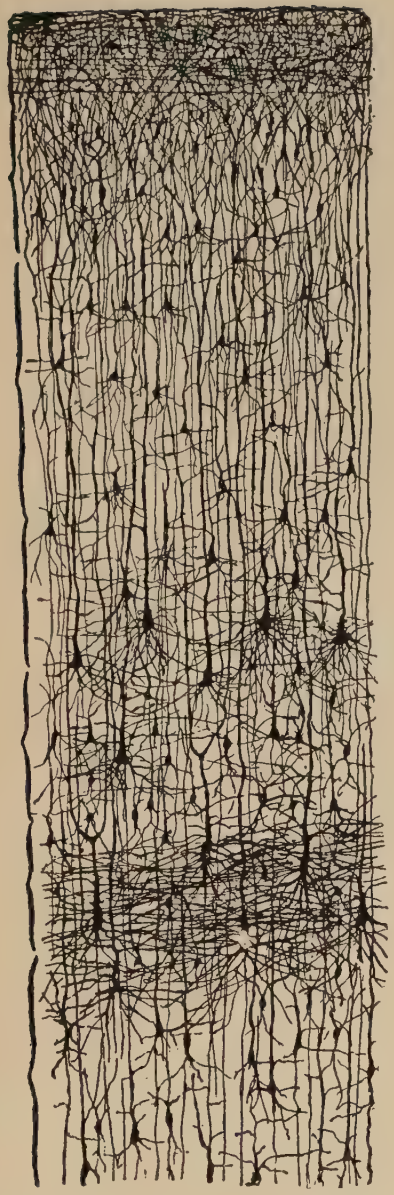
The body is thus, in one sense, a huge cell-state, with a cell-population thousands of times larger than the total human population of the world. A single act of thought involves the co-operation of a vast multitude of brain-cells; a single movement of a limb implies the contraction of thousands of muscle-cells, a single beat of the heart sends billions of blood-cells whirling down the dark pipes that we call blood-vessels. Each of these cells is a unit of life, comparable in some respects to a single free-living cell, such as an Amœba or a Slipper Animalcule. The enforcement of harmony and co-operation among such a vast multitude of units is the greatest achievement of evolving life. How necessary such enforcement is, and yet how difficult, is shown by the effects of cell-insubordination, as in cancer and malignant growths. In cancer, a few cells embark upon a career of unchecked growth and multiplication at the expense of the rest, and by so doing involve themselves and the rest of the cell-community in the common ruin of death.

§ 5

Reproduction

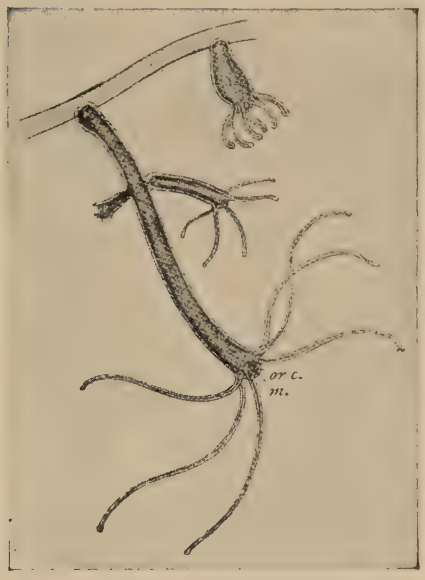
One of the fundamental attributes of living matter—perhaps the most fundamental of all—is its capacity for assimilation, for building up into its own complex likeness the simpler chemical compounds by which it is surrounded. What is more, in all primitive forms of life, assimilation is more rapid than its converse—new living molecules are constructed and put into place in the organism faster than the old ones are used up; the result is growth.

But to increase in size is to increase volume faster than surface, and this is, metaphorically speaking, to increase your population faster than you increase your import and export facilities.



From Quain's "Anatomy" (Longmans, Green & Co.).

A NUMBER OF CELLS WITH INTERLACING FIBRES FROM THE HUMAN CEREBRUM (Highly magnified.)

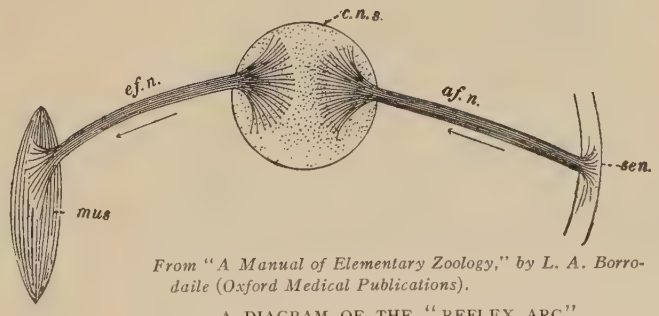


From "A Manual of Elementary Zoology," by L. A. Borrodaile (Oxford Medical Publications).

REPRODUCTION BY BUDDING

Two specimens of Hydra, magnified, one contracted, the other in a state of moderate expansion the latter bearing two buds in different stages.

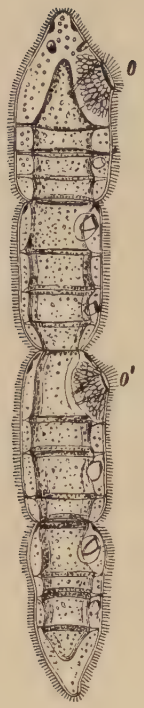
m. mouth; *or c.* oral cone.



From "A Manual of Elementary Zoology," by L. A. Borrodaile (Oxford Medical Publications).

A DIAGRAM OF THE "REFLEX ARC"

af.n. afferent nerve; *c.n.s.* central nervous system; *ef.n.* efferent nerve; *mus.* muscle; *sen.* sensory surface.



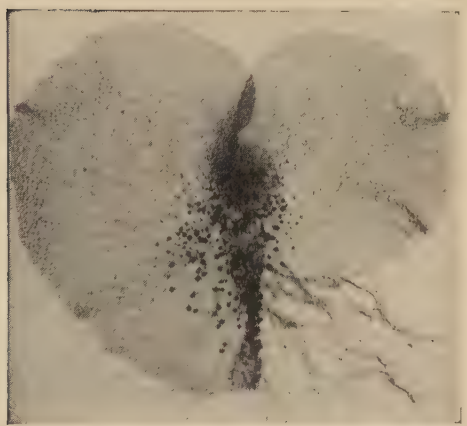
Reproduced from "Students' Text Book of Zoology" (Sonnenschein).

A CHAIN OF FLAT-WORMS PRODUCED BY FISSION, AS YET INCOMPLETE

(After Graff.)
o, o, mouth openings.

SORI OR SPORE-CASES ON FERN (POLYSTICHUM)

On the back of fern fronds, little brown spore-cases may be seen which burst open when dry and scatter numerous spores which, on germination, produce prothalli.



PROTHALLUS OF FERN: ORGANS PRODUCED FROM SPORE OF FRONDS

Showing archegonia (female organs) and antheridia (male), together with rhizoids (roots) on under side. (Greatly enlarged.)

Photos: J. J. Ward.

PROTHALLI (NATURAL SIZE), ON WHICH ARE SEEN DEVELOPING THE YOUNG FERNS WITH THEIR FIRST FRONDS

The difficulties inherent in large size are felt by life in all its forms; as a matter of fact the evolution of higher from lower forms abounds in devices for overcoming these difficulties.

The lowest forms of life, however, have never seriously faced the problem. As soon as the inconveniences of growth are felt, they are surmounted by the simple process of division into two halves, or, as it is technically called, of binary fission. Bacteria, unicellular animals and plants, and the cells of which the bodies of higher, multicellular organisms are built, multiply almost without exception by this method.

It will be seen that sex does not enter into this simplest and most obvious method of reproduction; furthermore, no substance is lost in the process; the one whole simply divides into halves, which then are reorganised into two new wholes.

Fission continues as a common method of reproduction among the simpler types of multicellular animals. Many worms, for instance, adopt it; in some cases the products of division may remain attached, forming a chain for some time. (See figure facing p. 685.)

But as Evolution proceeds, fission becomes more and more difficult. In an insect, for instance, or a cuttlefish, the processes of reorganisation after division would be impossibly complicated; and, while division and reorganisation were going on, the animal's powers of movement would be interfered with, and it would fall an easy victim to its enemies.

When the organism becomes more complicated, therefore, other methods have to be devised. The commonest method, which prevails in corals and many other Cœlenterates, in some worms, and in the degenerate relatives of the vertebrates known as Ascidians, is that of budding.

Budding is in essence unequal fission. The organism as a whole remains unaltered, except that one small portion of it is divided off and becomes reorganised into a new miniature whole. Usually the bud remains attached to the parent during its period

of growth and organisation; and in animals with more complicated types of budding, whole chains of buds are formed, and new individuals are thus produced in rapid succession.

Many disadvantages of fission are obviated by budding; but it would scarcely work with animals which possess a complicated skeleton; and besides, the ordinary body tissues of the highest animals have lost the power of unlimited growth, needful if buds are to be formed.

However, as soon as multicellular animals and plants had been evolved, the sexual process inevitably became associated with reproduction. The sexual process implies the union of two single cells into one, and thus to effect it two cells must be detached from the multicellular animals to which they belong, and the cell produced by their union must multiply and grow into a new many-celled individual.

A sexual process, however, does occur in many unicellular animals. In such as the Slipper Animalcule, for instance, the asexual reproduction by fission will take place once or twice a day, and may continue for a great number of generations through weeks or months or even years. At intervals, however, this cycle or unlimited multiplication is broken by what is called conjugation. Individuals come together, mouth to mouth, in pairs; their fluid internal substance comes in contact through their mouths; a complicated division of their nuclei (which, as we have seen in a previous chapter, are the bearers of hereditary qualities) occurs; and finally one nucleus from either member of the pair travels across and unites with a stationary nucleus in the other member. Thereafter, the two separate, and embark upon a new sexual cycle of fission.

A similar process occurs in most, perhaps in all, unicellular animals and plants: only in the Bacteria, which can hardly be styled cells, does it seem to be universally absent. Often the process is less complicated than in the Slipper Animalcule; two individuals simply come together and unite, first their bodies and

then their nuclei, so that one individual is formed from two. But in every case conjugation involves the fusing of nuclei from two individuals.

Conjugation is the simplest form in which we find the sexual process. Two facts merit remark. First, we see that sexual fusion need not involve difference of sex; the two gametes, as the cells are called which unite during the process, may be alike. Secondly, we see that sex is primitively not associated with reproduction.

In multicellular animals, however, the gametes are always of two different sorts, the male gametes or spermatozoa, and the female gametes or ova. The former are almost always very small, intensely active, and consist almost entirely of a head which contains the condensed nucleus, and a tail, by whose movements they swim. The latter are large, often very large, cells, and have sacrificed their motility in favour of the storing up of reserve material for the use of the embryo which is to grow out of them.

When multicellular animals have reached a considerable size and length of life, they can produce the microscopic gametes in enormous quantities and for long periods; a female sea urchin produces annually about as many eggs as there are human beings in London; and the number of sperms produced by any of the higher animals during its lifetime is considerably greater, not only than the whole present population of the world, but than the total number of human beings that can have existed since man first appeared upon the earth. In such animals therefore, the only form of reproduction is sexual.

In smaller and shorter-lived multicellular animals, however, sexual reproduction is still attended by certain drawbacks: only a few eggs can be produced at a time by a small female; and if the necessity for fathers could be done away with, twice as many individuals could be engaged in producing offspring. When, therefore, animals are too complex for fission or budding, and too small for the full advantages of sexual reproduction to be felt,

still another form of propagation, known as parthenogenesis, is often to be found.

Mothers but No Fathers

Parthenogenesis consists in this, that an egg develops without uniting with a sperm. In order to make sure of the fusion of nuclei which is the essential of sexual reproduction, eggs are usually rendered incapable of developing without some stimulus afforded by the sperm's entry. Parthenogenetic eggs need no stimulus and start to develop as soon as mature; so that once more, but in another form, we find reproduction as a special case of unlimited growth. Parthenogenesis is found in such creatures as plant-lice (Aphides) and a good many other insects, water-fleas, and wheel-animalcules, which all reproduce by its means throughout the summer and only produce males in the autumn; and as we shall see later, it can be artificially provoked in many other forms of life. A drone bee, too, develops from an unfertilised egg; it has a mother, but no father; whereas the queens and workers arise from fertilised eggs.

To sum up, we may say that reproduction is always the result of growth, and always must be the separation of one part of an organism from the rest. As life evolves, the part separated, at first equal to the rest of the organism, becomes proportionately smaller and smaller; and the sexual process, at first antagonistic to reproduction, becomes associated with it, at first in part and finally altogether.

§ 6

Regeneration

The power of unlimited growth is at the bottom not only of ordinary reproduction but of regeneration as well. We are apt to look upon regeneration as something marvellous, because it does not occur to any appreciable extent in ourselves, or in any of the higher animals with which we are familiar; but, as a matter

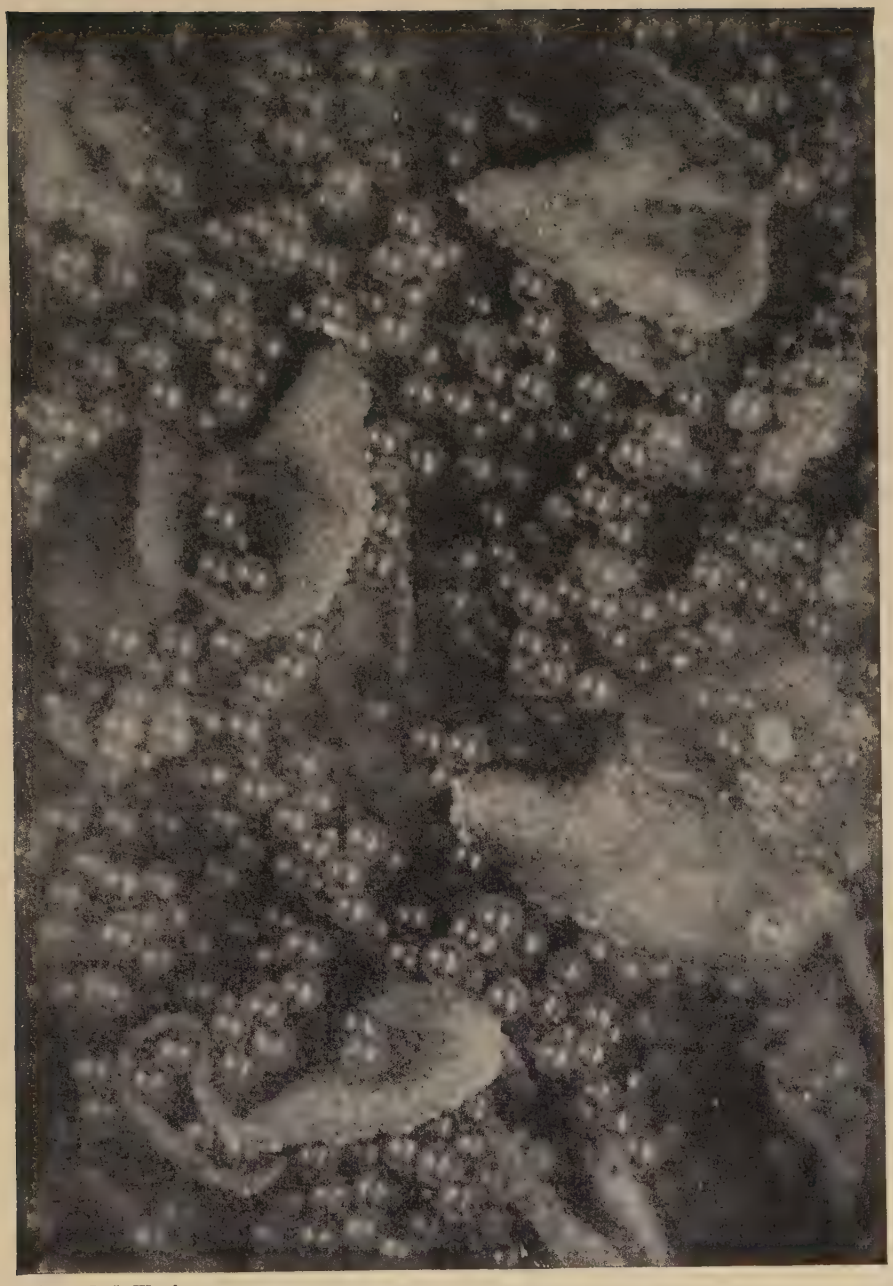


Photo: J. J. Ward.

A PHOTOGRAPH (HIGHLY MAGNIFIED) OF RIPE POLLEN-GRAINS FALLING FROM THE STAMENS OF A MALLOW FLOWER—AN ENORMOUS QUANTITY OF LIVING MATTER PRODUCED IN AND BY THE GERM-PLASM

Each grain is a germ-cell, conveying the male factors for reproduction to combine with those of the ovum-cell contained in the ovary.

From "Regeneration and Transplantation," by Dr. E. Korschelt.

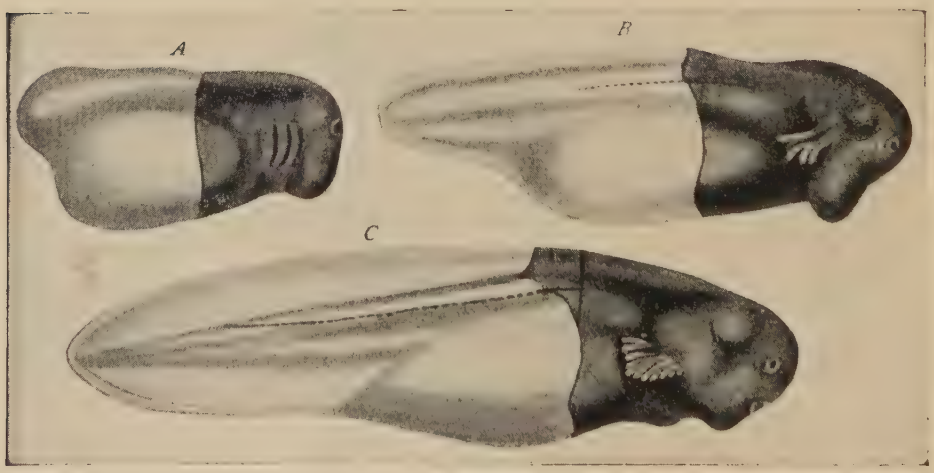
ILLUSTRATING REGENERATION.

A flat-worm cut so as to produce two extra heads and two extra tails. The mouth on the end of the protrusible proboscis or pharynx is seen in the center; a new mouth and pharynx have been formed in connection with the head on the left.
(After Voigt.)

From "Experimental Embryology," Jenkinson (Clarendon Press).

EXPERIMENTAL EMBRYOLOGY

Newt twins artificially produced by tying a thread round a newt's egg after it has divided into two, separating the two cells. (After Herlitzka, from Korschelt and Heider.) sf, the thread; g. jelly membrane.



From "Regeneration and Transplantation," by Dr. E. Korschelt.

ILLUSTRATION SHOWING DIFFERENT STAGES (A, B, C) OF GROWTH OF TADPOLES PRODUCED BY GRAFTING THE FRONT END OF ONE SPECIES ON TO THE HIND END OF ANOTHER
(After Harrison.)

of fact, it is a necessary and inevitable property of the lowest forms of life. The simplest way, perhaps, of realising the inevitability of regeneration is to remember that the appearance and structure of any animal or plant is the product of the balance between its own constitution and the environment that surrounds it. This is true, of course, for many portions of matter that are not alive. A drop of mercury on a saucer, for instance, assumes approximately the shape of a sphere, because of the laws of surface tension between mercury and air, and mercury and china; if we cut it in two, each half becomes a separate sphere. If a drop of mercury were an organism, we should say that its typical form was spherical, and that any fragment of the whole was capable of reorganising itself in the typical form.

If we take a single-cell animal, and cut it into two or into many parts, each part, providing it is above a certain minimum size and contains the whole or part of the nucleus, will readjust itself until it is once more in a state of equilibrium—in other words, until it is of the normal shape and structure of the species. Furthermore, the miniature animals thus produced, unlike the miniature drop of mercury, are capable of growth; so that in these simple forms regeneration is the necessary outcome of the two faculties of reorganisation and growth.

Even in many multicellular animals, a similar unlimited power of regeneration is to be found. Any piece of the stem of a polyp, any fragment of a Planarian flat-worm, will in almost all cases reorganise itself into a new whole.

Producing a New Head

In these larger organisms, the mechanism of the process is somewhat complicated. It appears that if a piece of flat-worm, for instance, be separated from the rest, it will first produce a new head-region; and that the head-region, once formed, will control the rest of the piece, so that all the rest of the parts of the body are formed in order from head to tail. One may say

that each part of the body is in some way dominant to all the parts that are posterior to it. If a cut is made on the side of the body, the tissues at the cut are often so stimulated by the shock of the operation, that they escape from their bondage to the dominant head, and produce a new head on their own account. In other cases the cut may be so made that new growth will occur at the cut surface, but the new tissue will still be under the influence of the old, and so a new but supernumerary tail will be produced. In this way extraordinary forms may be artificially produced, with extra heads and tails, or consisting of little else than two opposite-facing heads, like the Roman Janus.

It has even been possible to alter the whole polarity of an animal. A piece of the stem of a polyp, for example, will in ordinary circumstances produce a head only, or first, at its anterior end. But, if it is exposed to dilute poisons or narcotics, the whole piece will lose its differentiation and revert to a shapeless lump; when this is replaced in pure water it will regenerate, but the head will not form at either of the original ends but from the upper surface, where there is the most abundant supply of oxygen.

But perhaps the most remarkable power of regeneration is exhibited by many sponges and polyps, which can be dissociated into their component units without losing the power of regrowth. If a sponge be chopped into small bits, and the pieces then strained through the finest bolting-silk, nothing will come through the meshes save the cells of which the sponge is composed, either singly or in groups of ten or a dozen. The bottom of the dish into which they are strained will be covered with a film of these microscopic units; these will join up to form a number of little spheres, about the size of a sponge embryo; in each of these the cells will rearrange themselves in proper order, and the sphere, reorganising itself into a miniature sponge, will thus perform a veritable miracle of vitality.

§ 7

Remarkable Experiments

Other such apparent miracles, depending upon the reorganising power of living things, are seen as the result of grafting experiments. It is comparatively easy to graft pieces of earthworms together, and by this means worms have been produced longer than normal; shorter than normal; with a central piece reversed so that its front end points to the rear; and all apparently healthy. But this pales before the remarkable experiment of Harrison, who grafted the front half of a newly hatched tadpole of one species on to the posterior half of the tadpole of another species. The compound creature throve, grew, and metamorphosed into a normal frog. The only unusual point about it was the fact that, since the two species of frog differed in colour, one-half of the animal was light-coloured, the other dark.

In plants, even more intimate unions have been made. Winkler grafted a piece of one species of Solanum (the genus to which the potato belongs) on to a stock of another species, waited until the union had been well-established, and then cut the stem across, just at the point of junction. The bud which grew out was formed of the intermingled tissues of the two species, the outer layers being formed from one, the inner from the other. It was a real example of "being in someone else's skin." The compound plant, or graft-hybrid, was healthy, the only sign of abnormality being that, since the rates of growth of the two components were not quite the same, the skin did not fit accurately over the core and the leaves had a crinkled look.

As we ascend the scale of animal life, the power of regeneration dwindles. A crab or a newt will die if it is cut in two, but it retains the power of restoring lost limbs. It is at first sight very remarkable that the animal can restore just what was lost, no less and no more, but this becomes more intelligible if we think in terms of the idea of equilibrium. The balance is upset by the operation, and it is not restored until the missing part has been replaced.

If we alter the inner machinery of the animal, or if we alter the outer environment, the balance may not be the same as before, and we shall get abnormal results. For instance, below certain temperatures, a half flat-worm will not grow a new head at all, while at high temperature it will grow one which is larger than the normal. Here we have altered the outer world. The most remarkable example of an altered result due to an alteration in the animal is to be found in various prawns and shrimps. These have their eyes mounted on stalks, and the part of the brain connected with sight is to be found near the top of the stalk. If the eye alone is cut off, a perfect new one is regenerated, but if the eye is cut off together with the part of the brain in the stalk, what is regenerated is not an eye, but an organ identical with the first of the animal's two feelers or antennæ. This happens only when the regenerating nerve makes a connection with the rest of the brain, so that here it is clear that the different parts of the brain have an influence in determining what the regenerated part shall be like.

A somewhat similar example, showing the influence which one part may have over another, is seen in the formation of the lens of the eye in young newts and salamanders. The eye has a compound origin in development. The sensitive part or retina is derived from a cup-like outgrowth arising from the brain—the optic cup; the lens is formed as a thickening in the skin just over the cup. Various experiments have proved that the formation of the lens at the exact place in which it will be useful is due to some chemical influence (of the same nature, no doubt, as that exerted by the ductless glands—see p. 697) exerted upon the skin by the developing optic cup. If the skin is removed from the side of the head over the cup, and a piece from some other part of the body, or even from some other animal, is grafted on in its place, the new grafted piece will produce a lens. But if the optic cup is taken out and grafted under the skin elsewhere, for example, near the tail, no lens will be formed in the

FIG. 1.—FEMALE SMOOTH NEWT (*Triton tæniatus*) PHOTOGRAPHED BELOW WATER IN THE ACT OF DEPOSITING ONE OF ITS EGGS

FIG. 2.—EGGS OF SMOOTH NEWT ON THE LEAVES OF WATER PLANTS

The Newt bends down a leaf by means of its hind pair of legs and leaves an egg in the fold, as shown in the second photograph.

FIG. 3.—YOUNG NEWT TADPOLES NEARLY READY TO EMERGE FROM THE EGG

FIG. 4.—SMOOTH NEWT TADPOLES JUST AFTER LEAVING EGG

FIG. 5.—TADPOLE OF SMOOTH NEWT, SHOWING THE FEATHERY GILLS WHICH FLOAT UPWARDS ABOVE ITS HEAD

FIG. 6.—SMOOTH NEWTS NEARLY MATURED FOR TERRESTRIAL LIFE, JUST BEFORE LEAVING THE WATER TO BECOME LAND ANIMALS

FIG. 7.—SMOOTH NEWT MOULTING ITS SKIN AFTER RETURNING TO THE WATER FOR THE BREEDING SEASON

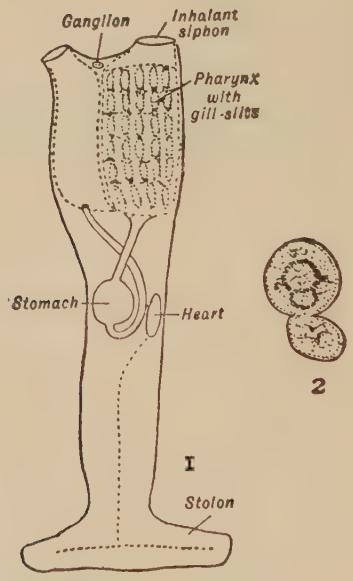
FIG. 8.—MALE AND FEMALE SMOOTH NEWTS AT THE HEIGHT OF THE BREEDING SEASON

Note the male newt's flowing crest and broad tail.

From "The School Science Review."

STARVING FLAT-WORMS

The illustration shows the reduction in size as the result of starvation in flat-worms. 1, before; 2, after prolonged starvation.



From "The School Science Review."

"LIVING BACKWARDS"
(See text for explanation.)

1. A normal individual of Clavellina.
2. The same individual de-differentiated.

head, but one will be produced over the optic cup in the tail region.

It is largely by such influence of one part upon another that the progressive increase of complexity in development comes about.

§ 8

Losing a Tail to Save a Life

In the highest groups of animals regeneration of large parts cease altogether. Birds and mammals can rarely replace anything but small losses. Sometimes the primitive power of regeneration is kept on for special reasons. Lizards, for instance, cannot regenerate their limbs, but they are specially liable to be caught by their tail as they disappear into their hiding-places. Accordingly, we find that the vertebræ of the tail are of special construction, so that they can be broken in two by a voluntary muscular contraction, and the whole tail thrown off; and furthermore, the tail, and the tail alone of all the organs of the body, can be regenerated. The animal loses its tail, but saves its life.

This restriction of the power to regenerate is to be found in individual development, as well as in racial evolution. The frog, for instance, cannot regenerate lost limbs, the tadpole can. Tadpoles, on the other hand, will not survive and reorganise after being cut in two, but the very earliest stages of development will survive this process. By tying a thread round the developing egg of a newt so as to constrict it into two separate parts, the egg may be made to give rise to two perfectly normal newts instead of the single one that it would normally form. This has a bearing upon human problems. As everyone knows, there exists two kinds of twins—those which are not more alike than ordinary brothers and sisters, and may be of either sex, and those (the so-called identical twins) whose resemblance is so striking as to lead to confusion and whose sex is always the same. This latter kind of twin is produced when the embryo in its very earliest stages of growth is, by some accident or other, separated into two

independent halves. A pair of identical twins represent a single human being which chance has decreed shall become two.

Our previous remarks about the restriction of asexual reproduction in higher forms thus require a little qualification; for even in the highest groups it may still occur in early stages. The different members of a litter of mammals generally arise from separate fertilised eggs. But in the Texas Armadillo, the quadruplets which the female always produces are formed by budding from a single embryo. Here, therefore, identical twins are normal, while in human beings they are accidental, but in both cases they are the result of the power of unlimited reorganisation and growth to be found in the early stages of all animals.

A consideration of these facts leads us on to other fields. For one thing, there is cancer. In cancer it appears that certain cells of the body escape from the dominating or controlling activity of the rest, and start unregulated growth on their own account. What is more, they seem in some particulars to revert to a more primitive condition, in which their powers of growth and multiplication are increased, and their capacity for performing the ordinary work demanded from the various cells which cooperate in a healthy body is correspondingly impaired.

What a delicate balance exists in the body of one of the higher animals is shown by the observations of Miss Slye on spontaneous cancer in mice. Some of the female mice which developed the disease were kept separate, while others were mated and allowed to breed. In the former lot the cancer grew at a great rate, and death occurred in about a month. But in the second lot, so long as litter followed litter without pause, the tumour's growth was negligible, to become active, however, as soon as reproduction ceased. In other words, the tumour and the developing embryos were competing for food-substances for their growth, and the embryos were so successful in their demands that they left next to nothing over for the cancer.

In any event, even though we are far from any proper under-

standing of the cancer problem, the general ideas drawn from the fields of regeneration, of dominance and subordination of parts, of the decrease of growth-power during development, and of the struggle between the parts of an animal, provide us with the point of view which may be the beginning of future progress.

§ 9

Old Age and Death

When fission occurs, as in unicellular animals, there is in a certain sense no death. There is at least no corpse. Individuals appear and disappear, but barring accidents, the same substance flows on through time in a stream of growth and fission. In multicellular animals, however, the germ-cells alone constitute this stream; the body persists for a time, but eventually, even if it escapes all accidents, dies an inevitable, natural death. In general, as we mount higher in the evolutionary scale, we find that the individual body has a longer span of life allotted to it; and further, this increased length of life is due much less to an increased period of growth than to a prolongation of the adult period. In lower animals growth is usually continuous, only terminated by death. But in all the higher, it comes to an end comparatively soon, and the prime of life is a period when change is reduced to a minimum and the animal can continue applying what it has learned to the business of life untroubled by deep-seated physiological alterations within itself.

In many lower animals, the changes that lead to ageing are definitely reversible, and age can be kept at bay under certain experimental conditions. In unicellular organisms, for instance, increase of size seems to be the cause which brings about fission and the disappearance of the individual. By cutting off a small part of the animal each time that it approaches full size, it is possible to keep it from dividing, apparently for an indefinite time. Or again, Planarian worms, in addition to their extraordinary powers of regeneration, are able to survive very long

periods of starvation by the simple procedure of living on themselves, gradually decreasing in size the while. As they get smaller, they also become more active. This activity seems to be a real sign of rejuvenescence, of renewed youth, for if they are alternately fed and starved so as to keep them within certain limits of size, they do not age, and persist, as Professor Child has shown, for as long as the experimenter has patience to continue his experiment.

Resting Stages

Other animals have the extraordinary property of "living backwards" in another way, of reverting to a more simple condition by a process which, since it is the opposite of differentiation, is styled de-differentiation. The Ascidian Clavellina, for instance, although a sedentary animal, is of considerable complexity, with gill-slits and heart, stomach and intestine, nervous and reproductive systems. When it is placed in unfavourable conditions, which yet are not sufficient to kill it, it shrinks, becomes more and more opaque, all the different kinds of cells of which it is made become more and more alike, until it at last comes to consist of a mere white lump, shapeless, and containing nothing but a few rounded bags and a mass of loose cells to represent all its original complexity. When placed in clean water again, it develops anew, and becomes once more a normal individual, of somewhat smaller size than before. These processes of de-differentiation are of great importance in many unicellular animals and in Bacteria; they lead to the formation of resting stages in which the organisms can tide over hard times. Further, since de-differentiation can be followed, apparently over and over again, by fresh differentiation, the simple individual can be made to live an indefinite period by such means.

These methods are not effective with higher animals. But even in insects, and probably in all other cold-blooded creatures, life may be greatly prolonged by low temperature. Professor Loeb, for instance, found that while the life of the little American

From Sir Edward Sharpey Schafer's "The Endocrine Organs" (Longmans, Green & Co.).

THE EFFECT OF THE PITUITARY GLAND UPON GROWTH

The dogs are from the same litter. From the one on the left a portion of the pituitary has been removed. (After Aschner.)

By permission of the Editor of the "Practitioner."

CASE OF MYXŒDEMA

a, before, and *b*, after treatment by thyroid extract.

REJUVENATING A RAT.

A rat, showing the symptoms of old age. By means of operations which stimulated the interstitial gland, or by grafting into rats reproductive organs from young animals, they became rejuvenated. (See illustration below.)

Reproduced from Steinach's "Verjungung.

The same rat, rejuvenated by Steinach's operation.

fruit-fly was 54 days at ordinary temperatures, it was only 21 days at 30° C., but could be prolonged to 177 days by keeping the animals at 10° C.

But in warm-blooded animals with an adult period in which no growth takes place, such as birds and mammals, the span of life cannot be lengthened in any of these ways. The adult period is one of very carefully adjusted balance, and when the balance is upset old age sets in, to be followed by inevitable death.

Interesting Experiments

In this connection one very interesting fact has been discovered in recent years, namely, that many of the tissues of which the body is composed are potentially immortal, although the body itself is doomed to death. By careful methods it has been found possible to cultivate in nutritive fluids, outside the body, small pieces taken from a living animal, transplanting them to new portions of fluid every few days. Carrel in New York has cultivated a piece of connective tissue, taken from a chick before hatching, for longer than the full normal lifetime of a hen; and what is most remarkable, the rate of growth and multiplication of the cells composing it did not decrease. We must suppose that the balance and interaction of the different tissues, each checking and counter-checking the other, lead to death, whereas the unchecked multiplication of any one sort of cell, if the right conditions of food and expansion are provided, can continue indefinitely.

If we wish to prolong the existence of the whole, which is our only practical concern, we must attempt to discover what are the organs involved in maintaining the balance of adult life, and then try to help them as they begin to fail.

§ 10

The Ductless Glands

Our knowledge is still very scanty, but it seems quite clear that the chief organs concerned are on the one hand the so-called

ductless glands, and on the other the nervous system—the brain especially. The ductless glands are organs which pour their secretions directly into the blood; and many of these secretions, or hormones as they are often called, have an extraordinary power over the growth of the body, its rate of working, and the co-operation of its parts. The pituitary gland in the brain, for instance, has a great influence upon growth, especially upon the skeleton; giants usually seem to be produced by an excessive development of this gland. The thyroid may be considered as the draught of life's fire. If it is deficient, the fire burns low, and there results a disease known as myxœdema, in which bodily and mental processes are all sluggish. Too much thyroid, on the other hand, leads to wasting away (in spite of increased appetite), to increased pulse-rate, and to nervousness. Part of the reproductive organs, the so-called interstitial tissue, also acts thus as a gland, and produces a secretion which influences the growth of all the bodily characters associated with one sex or the other, and stimulates the brain, bringing into activity the sexual instincts.

Steinach in Vienna has found that rats which had begun to show signs of senile decay could be rejuvenated by means of operations which stimulated the interstitial gland, or by grafting into them reproductive organs from young animals. As a result, all the other ductless glands in the body were stimulated to renewed life, and the failing brain and all its mental faculties were revivified. By this means, he was able to prolong the life of rats by about 40 per cent. These results so far stand alone; they need confirmation on other animals, and long testing to see whether they are applicable to man; but at least they open a window on to new fields of work, and show what revolutionary results may be expected when biological research finds men, money, and time (for it is a laborious, expensive, and delicate business!) to investigate in fullness of detail the complicated machinery of the mammalian body.

Such work, however, promises at best an increase of the span of life. Death is bound to come at last. In this connection the work of the great Russian scientist Metchnikoff should be remembered. He investigated all the cases which he could find (and they are relatively uncommon) of men and women who died a really natural death, of pure old age uncomplicated by disease or accident. And, as a result, he asserted that such a death is really natural—that it is not painful, and what is more, that it is not dreaded, but looked forward to as one sleeps after a long day. Finally, he asserted—what would be difficult to deny—that nine-tenths of the accidents and diseases that beset mankind could be prevented; and if they were, then natural death, instead of being the accidental fortune of a few, would be the birthright of our average humanity.

In matters biological, we are only just emerging from the age of mythology, through a period of observation, into one of experiment; and this in its turn is opening up vistas of future control, hitherto undreamt of, over the processes of life itself. In the little domain with which we have been dealing, we can see clearly held out to us, as the reward of patient labour, the possibility of prolonging the normal life of man, and of robbing death, which so often shadows human thoughts, of the worst of its terrors.

(The problem of Heredity and Mendelism was discussed in the chapter, "How Darwinism Stands To-day.")

BIBLIOGRAPHY

Child, *Individuality in Organisms* (Chicago, 1915).
Huxley, *The Individual in the Animal Kingdom* (Cambridge, 1912).
Metchnikoff, *The Prolongation of Life* (London, 1910).
Minot, *The Problem of Age, Growth, and Death* (London, 1908).
Morgan, *Regeneration* (London and New York, 1901).

XX

THE CHARACTERISTICS OF LIVING CREATURES

THE CHARACTERISTICS OF LIVING CREATURES

The All-Round View

WE may take an animal to pieces—as the anatomist is always doing, and a wonderful analysis it is, especially when we place other lenses in front of our own; we may inquire into the "go" of the various parts—as the physiologist seeks to do, and we have seen what an intricate engine the body is; we may watch the almost transparent egg of a moth gradually divide and redivide and develop into a tiny caterpillar —which even more marvellously becomes a butterfly—the embryologist's task; and we may work among fossils till we are able to throw upon the present the light of a distant past—which is the palæontologist's ambition. These methods are all essential if we are to begin to understand living creatures, but they are not altogether adequate. We must also have an all-round or synoptic view of living creatures; we must see life whole. What would we think of an astronomer who kept to his spectroscope and never enjoyed the splendour of the star-strewn sky? And it is even more important for the biologist than for the astronomer to have the synoptic view, because life is such an elusive kind of activity. We cannot hope to get to grips with it unless we approach it in every possible way. So, laying aside analysis, let us consider the characteristics of living creatures when we look at them in an all-round impressionist way. In so doing, we shall follow, with the permission of the publishers (Messrs. Williams & Norgate), J. Arthur Thomson's *System of Animate Nature* (vol. i, 1920, pp. 50-56).

It is surely a magnificent spectacle that Animate Nature presents. What a gamut of life from the microscopic Infusorian to the giant whale, from the hyssop on the wall to the cedar of Lebanon! What abundance of life is revealed when the dredge comes up, or when the insects rise before us in a cloud as we walk through the grass land in a hot country! What variety of architecture, what abundance of individuality, within the same style! All is suggestive of fertile imagination. How strong the pressure, as the waves of life surge up against their shores—we call this the "struggle for existence"; how numberless the hand-and-glove fitnesses or adaptations; how subtle the linkages in the web of life; how constant the changefulness or variability; how universal the beauty! But let us think over the deeper impressions which fill the mind after the crowd of details sinks to rest. These deeper impressions form part of the materials which Biology gives over to Philosophy to build with.

A MULTITUDE OF INDIVIDUALITIES, YET A SYSTEMA NATURÆ

Innumerable Species

When we look at Nature with a fresh eye, in a new country, or in some novel experience such as dredging, we have a transient impression of overwhelming confusion, as if Aladdin's cave had been suddenly burst open before us. Many miss this in ordinary circumstances because familiarity breeds the contempt of inattention, and also because a very large number of living creatures live a hidden life. For every conspicuous plant there are a score inconspicuous, and for every readily visible animal there must be a hundred unseen. It is not of individuals that we are thinking, but of individualities, of species. On a very moderate estimate of species, there are at least 25,000 named backboned animals, ten times as many named backboneless animals, and about as many plants. There are 100,000 Dicotyledonous Flowering Plants. Darwin speaks of finding twenty different kinds of

From "Animal Life by the Sea-shore" (Country Life).

"THE ABUNDANCE OF LIFE."

Acorn-shells or rock-barnacles. These sedentary crustaceans cover the rocks and are exposed at low tide. When the tide is in they waft food-particles into their mouths by means of six pairs of curl-like limbs. When the tide is out they close the four valves which form the roof of each rampart-like shell. Huxley spoke of them as fixed by their heads, kicking their food into their mouths with their legs. The larvæ swim freely in the sea.

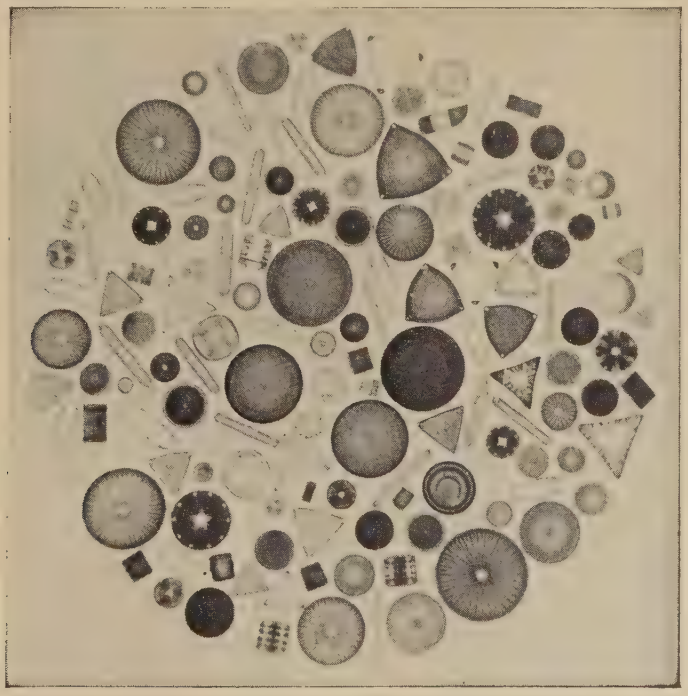


Photo: J. J. Ward.

A GROUP OF DIATOM SHIELDS.

There is a great multitude of life in the sea. The above illustration shows the variety of Diatom shields; these are the siliceous skeletons of minute unicellular plants. The group in actual size, arranged in a circle, is only ⅛ of an inch in diameter. At the autumnal climax of productivity in lakes there may be to the square yard 7,000 millions of one well-known Diatom.

Reproduced from the Smithsonian Report, 1919.

A COLLECTION OF DRAGON-FLIES OF THE ORDER ODONATA, WITH THEIR BEAUTIFUL GAUZE-LIKE WINGS. THEY ARE PERHAPS THE BEST FLIERS AMONG INSECTS, PLAYING A USEFUL PART IN KEEPING DOWN INJURIOUS PEST WHICH THEY CATCH ON THE WING

flowering plants on a patch of turf four feet by three, and there may be as many different kinds of animals on one stone brought up from the sea-floor.

The study of marine animals has been enthusiastic and intense for many years, but those who know most about it will agree with what the poet Spenser said long ago:

> But what an endless worke have I in hand,
> To count the seas abundant progeny,
> Whose fruitful seede farre passeth those on land,
> And also those which wonne in th' azure sky;
> For much more eath to tell the starres on hy,
> Albe they endlesse seem in estimation,
> Than to recount the seas posterity;
> So fertile be the floods in generation,
> So huge their numbers, and so numberlesse their nation.

The problem of individuality or species is very difficult; but our view of Nature as a whole must take account of the fact that species are multitudinous and that they represent discontinuous individualities, with much more constancy than the earlier Darwinians supposed. Linnæus said: "There are as many species as there were ideas in the Divine Mind," and there is no doubt that a good species is like a clear-cut idea. At the other extreme of comparison, it is like a chemical element, but on a higher plane. As Goethe said: "The one thing Nature seems to aim at is Individuality; yet she cares nothing for individuals." If we personify "Animate Nature," it must at least be as an artist with inexhaustible imaginative resources, with extraordinary mastery of materials.

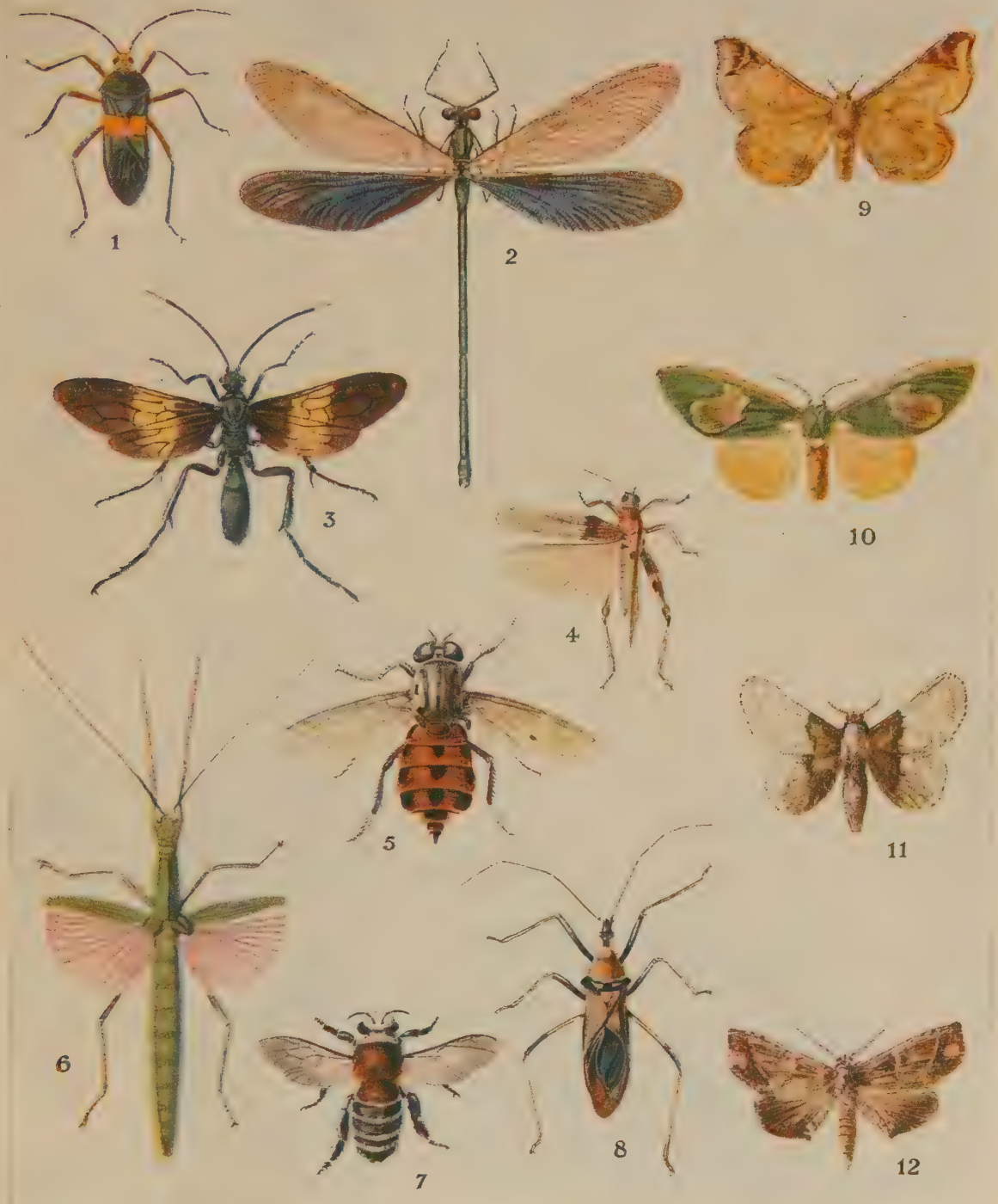
But in the prodigal wealth of individuality, it is not a dæmonic confusion, but a rational order that we see. The species are remarkably unique and discontinuous, each with a character of its own, yet they are often like stages in individual development, and they can often be classified in a logical series. Linnæus established his Systema Naturæ quite apart from any evolutionist

conception, and though the fact of what we may call "blood-relationship" lies behind every so-called natural classification, our present point is simply that orderly classifiability is undeniable. As Goethe said: "Each of her works has an essence of its own; each of her phenomena a special characterisation; and yet their diversity is in unity."

Abundance and Insurgence of Life

A second impression is that of wealth of numbers and of indomitable will to live. There are, indeed, organisms which multiply slowly, such as elephants, golden eagles, and century plants, but this is not the way with the majority. Most of the streams of life are ever tending to overflow their banks. Even the rarities may do so in appropriate conditions; thus a rather rare wingless Glacier-Insect was recently found on one stretch of the *mer-de-glace* at Chamonix, in numbers almost equal to the population of Great Britain and Ireland. In the case of organisms of low individuation, which hold their own rather because they are many than because they are strong or wise, the prodigality of productivity is beyond all our powers of conception. From one infusorian there may be a million by the end of a week, and in some of the floating meadows of the sea there may be a quarter of a million units in a gallon of water. There is a well-known British starfish, *Luidia ciliaris,* which produces at least two hundred millions of eggs, and yet it is not what one would call a common animal.

We are familiar with calculations of what would occur if there were no thinning of the crops—how soon the earth would be covered with a weed, or the sea filled solid with a fish, or the sky darkened with an insect, and recurrent plagues or locusts, sparrows, rabbits, and moles remind us that a possibility may easily become an actuality. After allowing a prodigious mortality of 95 per cent. it is computed that the 10,000,000 pairs of breeding rats in Great Britain on New Year's Day, 1918, were



Reproduced from the Smithsonian Report, 1919.

A GLIMPSE OF THE VARIETY OF LIFE

There are hundreds of thousands of different kinds of creatures, each an individuality—itself and no other. On an extremely moderate estimate, there are a quarter of a million different species of backboneless animals, the majority being insects.

1, a true bug with piercing and sucking mouth-parts; 2, a dragon-fly; 3, a digger wasp; 4, a grasshopper; 5, a tropical two-winged fly with the hind-wings represented by quivering "poisers"; 6, a walking-stick insect; 7, a solitary bee; 8, a predaceous bug; 9–12, tropical moths.

represented by 40,000,000 pairs at the end of the year, and by 12,000,000 more pairs the following month! There is a grimness in the well-known remarks of Linnæus that three flies will consume the carcase of a horse as quickly as a lion can. Professor Woodruff observed the common asexual generations of the common slipper-animalcule (Paramecium) for five years between 1907 and 1912 and found that there were 3,029 of them, over three every forty-eight hours. Careful calculation showed that they had given evidence of the capacity of producing in the five years a volume of protoplasm approximately equal to 10,000 times the volume of the earth. This power of self-increase must be taken account of in our conception of living organisms, and the resulting abundance of life must form part of our impressionist picture of Animate Nature. At the autumnal climax of productivity in lakes, there may be to the square yard 7,000 millions of a well-known Diatom, *Melosira varians,* so that the water is like a living soup.

We have to remember, moreover, the obvious but notable fact that we are dealing not with items like grains of sand, but with individuals, each itself and no other. Mendel put an end to the phrase "as like as two peas."

Individuals differ greatly in degree of complexity and of integration. Many an Infusorian has an intricate organisation and lives a by no means monotonous life, though it is only what we somewhat fallaciously call "a single cell." Hardly any larger than some Infusorians are some of the Rotifers, sometimes with about 1,000 cells; a minnow has its millions, and a bird its millions of millions. What a contrast between the very incipient integration of a sponge, the intricate division of labour in a "Portuguese Man of War" hesitating between colony and individual, and the compact co-ordination of the circumspect wren. As a recent student of the subject, Mr. Julian S. Huxley, puts it, we are confronted in Nature with closed independent systems with harmonious parts and with capacity for continuance. Such

are individuals. "Though the closure is never complete, the independence never absolute, the harmony never perfect, yet systems and tendency alike have real existence." The individual is unity in diversity—in what it is and what it does—a whole whose diverse parts all work together, ensuring continuance. When it transcends the limits of its substance, Mr. Huxley says, *that is personality.*

But in addition to the abundance of life—alike of individualities and of individuals—there is the quality of insurgence. Living creatures press up against all barriers; they fill every possible niche all the world over; they show that Nature abhors a vacuum. We find animals among the snow on Monte Rosa at a height of over 10,000 feet; we dredge them from the floor of the sea, from those great "deeps" of over six miles where Mount Everest would be much more than engulfed. It is hard to say what difficulties living creatures may not conquer or circumvent. You may find insects in hot springs in which you cannot keep your hand immersed, or Rotifers and other small fry under fifteen feet of ice in the little lakes of Antarctica; you find a Brine-Shrimp and two or three other animals in the Great Salt Lake; you find a fish climbing a tree, and thoroughly terrestrial types like spiders having species living under water; there is, as Sir Arthur Shipley has shown, a bustle of life on the dry twigs of the heather. When we consider the filling of every niche, the finding of homes in extraordinary places, the mastery of difficult conditions, the plasticity that adjusts to out-of-the-way exigences, the circumvention of space (as in migration), and the conquest of time (as in hibernation), we begin to get an impression of the insurgence of life. We see life persistent and intrusive—spreading everywhere, insinuating itself, adapting itself, resisting everything, defying everything, surviving everything!

The great Sequoia trees (see illustration, facing p. 604) may be taken as emblems of life's tenacity, for they have been known to flourish for over two thousand years. One of the oldest

Reproduced from the Smithsonian Report, 1919.

ANOTHER ILLUSTRATION OF "THE ABUNDANCE OF LIFE"

A collection of beetles from near Washington, belonging to the one order Coleoptera. 1, a snail-eater; 2, a tree-climbing caterpillar-hunter; 3, a conspicuous snapping-beetle whose larvæ devour the grubs of wood-borers; 4, a stage-beetle; 5, a "long-horn," very inconspicuous on the bark of pine-trees; 6, a "Russia-leather" beetle with that characteristic smell; 7, a dull-black beetle breeding in rotten wood; 8 and 9, stag-beetles with big jaws in the male, small jaws in the female; 10, the Betsy-bug beetle, boring in decaying logs, unique in the parental care exhibited by both males and females, and remarkable also for the sound produced both by adults and young; 11, the "tumble-bug" beetle that flies at night and is often attracted to lamps.

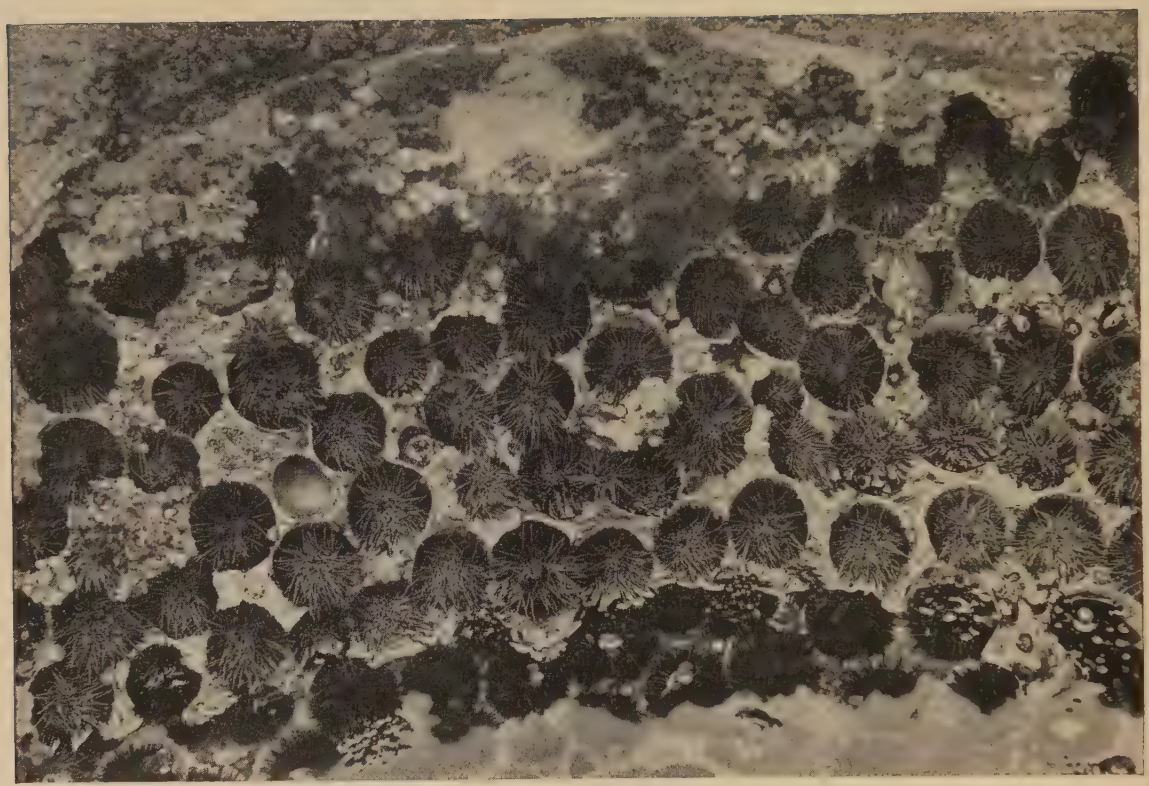


Photo: W. A. Green.

THE BORING PURPLE SEA-URCHIN, STRONGYLOCENTROTUS LIVIDUS, IN A ROCK POOL, BUNDORAN

These Urchins bore cavities for themselves in the Carboniferous Limestone, and are sometimes permanently sealed up in their holes by the growth of a calcareous seaweed that covers the rocks. In some cases one side of the cavity is wholly composed of the calcareous Alga. The method by which the hole is bored is uncertain, but it is probably chemical. The subject requires re-investigation.

had 2,425 annual rings when it was killed, and must have begun to live 525 years before the Christian era. "We have," wrote Professor W. R. Dudley, "deep in their annual rings, records which extend far beyond the beginnings of Anglo-Saxon peoples, beyond even the earliest struggles for liberty and democracy among the Greeks—records of forest conflagrations, of the vicissitudes of the seasons, of periods of drought and periods of abundant and favouring rains." In our conception of life we must not forget these sublime instances of its power to endure.

XXI

THE ROMANCE OF CHEMISTRY

THE ROMANCE OF CHEMISTRY

WHEN we first visit a great museum we are impressed by the multitude of different kinds of things: these thousands of startlingly different species of animals—each itself, and no other—these hundreds of different kinds of wood, shelf after shelf of minerals, an Aladdin's cave of precious stones, besides all manner of things artificially made, such as alloys and fabrics, drugs and preserved foods. Some of the objects we see may fade into one another, but what almost embarrasses us is the number of things that are quite distinctive. We get the same impression of diversity when we take a walk in the country, or when we see a dredge or a trawl brought up on deck.

Shuffling the Chemical Cards

Now a kindly curator in the museum might take us to the bird-cases, for instance, and show that, after all, the diversity was in great part due to different shufflings of a not very large pack of cards. There are thousands of tunes, but there are not many notes. He might take us to the case of minerals, where, by ourselves, we got the impression of overwhelming and baffling variety, and show us that a comparatively small number of really different things may be shuffled into a multitude of diversities. A small cast of players may form a great variety of different tableaux.

There might be in the museum a case showing a sheet of parchment-paper, a slab cut out of a tree, a wooden pot full of glue, a cork for the same, a piece of india-rubber for erasures, a celluloid beaker full of water, a "lead" pencil, a vulcanite pen-

holder, a pad of blotting-paper, a lump of sugar, a little starch, and a hundred other things—"as different as different could be"—including even a diamond; and yet the label of the case might correctly state that all this variety included only three elements—Carbon, Hydrogen, and Oxygen.

Perhaps this is one of the big revelations of chemistry for ordinary people, that in spite of the immense variety of things in the world there is only a relatively small number of things that are really different, namely, *the eighty or so chemical elements.* We do not know how many words there are in the English language, but there are only about twenty-six generally recognised letters. It is the same in chemistry. Many different hands, but not such a large number of cards!

Furthermore, just as there are some letters, like *q* and *z*, which are not in very frequent use, in the same way it must be noted that many of the fourscore or so chemical elements are rare, and do not occur in more than a small percentage of the specimens in the museum. Many of the "rare earths," though very important for man's purposes, do not play a large part either in the architecture or in the bustle of the world. They lurk quietly in remote corners—take tantalum, for instance. It has been calculated that there are, on a very moderate estimate, a quarter of a million of very different kinds of things in this world of ours. But scientific chemistry has shown that this multitude is due to varied groupings of about eighty "really different kinds of stuff," namely, the chemical elements. It is not easy to put the case rightly, for each fresh pattern may be something very definitely new and individual, just as a painter makes many pictures of the same few colours. Every one knows the variety of patterns that result when the pieces of coloured glass in a kaleidoscope are shaken into new combinations, but this is a *static* diversity. It suggests, however, what may result from the shuffling of a few elements, especially when some of these are what is sometimes called "attractive." In general terms, the conclusion, to which common

experience and exact science lead us, is this: that, given a small number of sociable elements there may be many a menage. From a few elements, even from fewer than we can count on the fingers of our two hands, there may be a new world. And the view is widely held among chemists that there has arisen from one elemental stuff the whole array of known elements.

§ 1

In a previous chapter, THE FOUNDATIONS OF THE UNIVERSE, the problems which the Physicist and the Chemist of to-day are so eagerly investigating were fully discussed. We saw there how it has come about that all the observed phenomena of Chemistry and Physics are regarded as indications of the fundamental unity of matter. All matter, in short, is supposed to be, in its final analysis, essentially the same in constitution. The atoms of all matter consist of particles of positive and negative electricity; the simplest atom, that of hydrogen, is a unit of negative electricity, called an electron, revolving round a nucleus of positive electricity, called a proton. Electrons obtained from different atoms are found to be the same; in an atom of hydrogen there is one electron, in an atom of helium two, in an atom of lithium three. The addition of further electrons to the system gives rise to the atoms of all other elements. All matter is thus supposed to be electrical in its nature. The atom, since its disintegration is seen to take place, is no longer the atom indivisible or incapable of being broken up into something simpler. It is not now believed that each of the eighty or so elements known to us has its own kind of atom, each stamped with its own properties. The properties and qualities of the different elements, it is believed, depend on the number and arrangement of the particles of negative electricity (electrons) and of positive particles (protons) contained in the atoms of the various elements. The view is that all the elements, though they have different chemical qualities, are built up out of the same

material; thus our ideas regarding the constitution of matter and the framework of the Universe have been completely changed. "The superlatively grand question" is, what is the inner mechanism of the atom?

It is the business of the Chemist to attempt to fathom the mysteries of the properties of the various chemical elements, to evolve order and system out of them. It is to the Chemist that we owe our knowledge that the atoms of different substances can be arranged in a definite order, and also that they show an increasing complexity of structure. Heavier atoms appear to behave as though they were evolved from the lighter.

Forms of Matter

It is well known that under suitable conditions, the same type of matter can exist in three distinct forms—solid, liquid, and gas. In passing from one state to another, it is a matter of common knowledge that there are remarkable changes in appearance and physical qualities of an element. These changes are believed to be connected with the average distance which separates one atom or molecule from the other, and in the rapidity of motion. In the gas or vapour form, the molecules are on an average so far apart that their mutual attractions are relatively unimportant. The lowering of the temperature, the distance and rapidity of motion of the molecules, diminish, until under certain conditions the attraction of the molecules for one another predominates, resulting in a much closer packing and the appearance of the liquid form. The molecules, however, still retain a certain freedom of motion, but this is diminished with lowering of the temperature, until at a certain stage the molecules form a tighter grouping, corresponding to the solid state, where the freedom of motion of the individual molecules is much restricted. In order to account for the resistance of solids to compression or extension, it has been supposed that the force between molecules is attractive at large distances, but repulsive at small distances. While we are able to offer a general explanation of the passage of an element from one state to

Photo: Rischgitz Collection.

JOHN DALTON (1766–1844)

One of the greatest of British chemists, the son of a Quaker weaver, famous for his development of the Atomic Theory. He maintained that atoms are minute particles of matter which cannot be further subdivided; that atoms of the same element are all alike and of equal weight, while those of different elements are unlike; and that compounds are formed by the union of atoms of different elements in simple numerical proportions. Dalton also made very important physical researches on gases and vapours. He was a scientific discoverer of the first order. He "never found time" to marry.

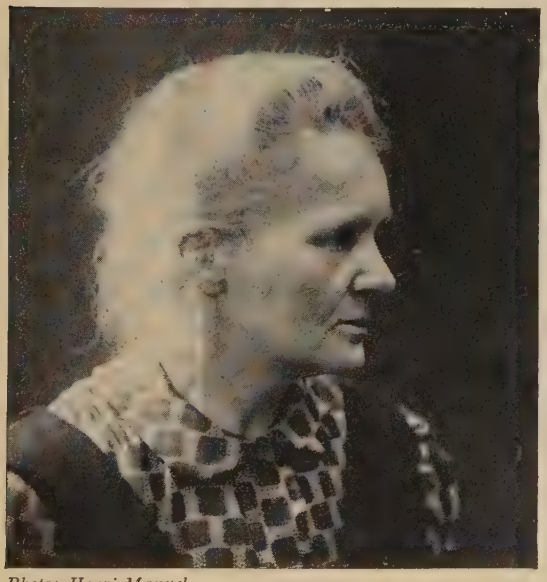


Photo: Henri Manuel.

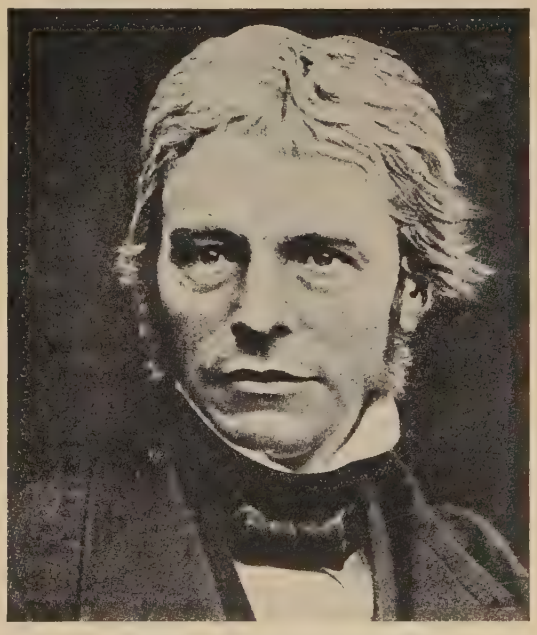
MME. SKLODOWSKI CURIE

Along with her husband, M. Pierre Curie, Professor in Paris, Madame Curie discovered Radium. From pitchblende they extracted radium chloride. Radium is present in pitchblende in very minute quantity, not more than one part in five or ten million of the mineral. Mme. Curie went on to establish the atomic weight of radium (226) and to make further discoveries of lasting importance.

Photo: Russell, London.

PROFESSOR FREDERICK SODDY—ONE OF THE MOST BRILLIANT OF PRESENT-DAY CHEMISTS

He has made great contributions to physical chemistry, notably in connection with radio-activity. He was trained under Sir William Ramsay and Sir Ernest Rutherford and has shared in their discoveries. He is one of the professors of chemistry in the University of Oxford, and besides being a distinguished maker of new knowledge is widely concerned with what Bacon called "the relief of man's estate."



MICHAEL FARADAY (1791–1867)

One of the greatest men of science that England has produced. The son of a journeyman blacksmith, he became in 1813 assistant to Sir Humphry Davy at the Royal Institution and remained at work there, experimenting and lecturing, for over fifty years. He had a very wonderful mind and a singularly attractive character. His researches on gases and their condensation, on electricity, magnetism, and electro-magnetism are of the first importance, and a monument to genius of the highest order. Everyone knows his *Chemical History of a Candle.*

Photo: J. J. Ward.

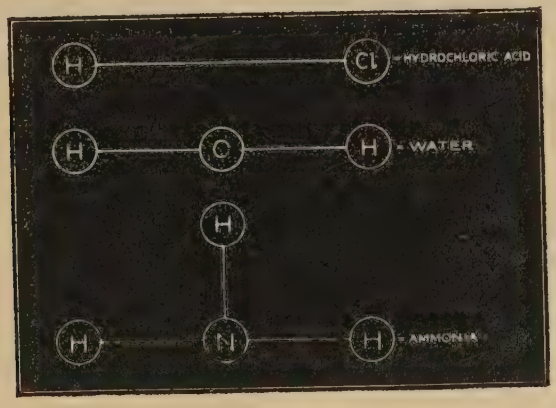
A FAMILIAR INSTANCE OF THE CONVERSION OF A LIQUID INTO A SOLID

A mass of water is here shown frozen into ice and standing on the bucket from which it was turned out. Note the dark portion in the centre where the water has now completely frozen. As the water freezes it rises to the top and forms a blanket of ice which protects the water underneath. The ice also forms round the margins of the bucket, where the loss of heat by radiation is greater than in the interior. In shallow water a sheet of ground ice may be formed on the bottom as in the bucket. In a deep pool the bottom water does not freeze.

another, a complete explanation of such phenomena will only be possible when we know the detailed structure of the atoms and the nature and magnitude of the forces between them.[1]

It is well known to everybody that the atom of one chemical element may combine with one or more atoms of another element. When the chemist speaks of the *valency* of an element, he means the number of other atoms, with which one atom of this element can directly combine. For example, one atom of hydrogen combines with one atom of chlorine, and the result is hydrochloric acid; or one atom of oxygen will combine with two atoms of hydrogen and the result is water; one atom of nitrogen combines with three of hydrogen, and we get ammonia.

These combinations are usually graphically expressed thus:



Each of these combinations represents a *chemical* process, that is to say, a chemical change which produces a substance which is totally distinct, not a substance which merely partakes of the characters of the two component elements.

Thus are the various substances built up; the elements are mostly found in mutual combinations, and the combinations are sometimes of course, very complex. While a particle, or molecule, of water consists of two atoms of hydrogen and one of oxygen, the molecule of the proteid called "albumen" is built

[1] Sir Ernest Rutherford.

up by 72 atoms of carbon, 112 atoms of hydrogen, 18 atoms of nitrogen, all brought into association with one atom of sulphur. In all protoplasm of living matter there is a mixture of proteins, carbohydrates, and fats, with intricate chemical and physical inter-relations. It is highly improbable that there is any one substance which deserves to be called *the* living matter or protoplasm. What we actually know is a complex and heterogeneous system in which various chemical reactions take place simultaneously. There is always involved, as life goes on, a breaking down and a building up of proteins. But the riddle is still unread.

Some biologists hold the view that there is an "ultimate molecule of life," hidden in the protoplasm, which holds the secret of the endless building up and breaking down. Sir Ray Lankester gives this "supreme life-stuff" the name "plastogen," and he says in regard to its workings that "whilst they can be grouped with the chemical and physical qualities of other bodies, they so far transcend them in complexity and in immensity of result—the whole creation of plant and animal life—that their appearance constitutes, in effect, a new departure, a sudden, and to us, unaccountable acquirement. But then we must remember that it is also an unaccountable thing to us that water suddenly becomes ice at a low temperature and suddenly becomes vapour at a high temperature, even if we are able to imagine the mechanism which necessitates these changes. We cannot 'explain' the nature of things. Even though we can classify them and arrange them in order, and more or less satisfactorily guess what their inner mechanism is, we cannot, in our present state of knowledge, trace them in detail to a first beginning."

§ 2

Some of the elements in their natural conditions are gaseous, like oxygen, hydrogen, nitrogen, chlorine, etc.; mercury and

bromine are liquids; while a great number, chiefly metals, are solids, like gold, iron, zinc, etc.

Professor Meldola says with respect to the distribution of the elements:

> It is of interest to note that more than three-fourths of the accessible crust of this globe upon which we live is made up of two non-metals, oxygen and silicon, about one-half being oxygen. Nothing affords more striking evidence of the marvel of chemical change than the contemplation of this geo-chemical fact, that the superficial "solidity" of the earth is due to the predominance of those mineral constituents into the composition of which gaseous oxygen and the non-metal silicon enter to a preponderating extent. The whole crust of the earth with which geology deals is composed to the extent of more than 99 per cent. of only about twenty out of the eighty-two elements. This will give an idea of the rarity of some of the materials which the chemist has had to deal with.

Mixtures and Compounds

There is an obvious but important difference between a *mixture* like sand plus sugar, like iron dust plus chalk, and a *compound* like sugar, or like chalk. A mixture is never homogeneous; it can be divided into different ingredients. A compound is always homogeneous; its particles, however fine, are all the same —all the same until we begin to break up the compound into its components. With water we can dissolve away the sugar from the sand; with a magnet we can pick away the iron particles from the chalk; but it is usually necessary to take more thoroughgoing measures to split up a compound.

It must not be supposed, however, that the distinction between a mixture and a compound is always easy. Air looks very homogeneous, but it is a mixture of a great crowd of oxygen particles, a still greater crowd of nitrogen particles, and small crowds of carbon dioxide and water-vapour particles. Nothing

seems more homogeneous than water, but pure water is never found in nature. There are always impurities in it, and one needs only to bring a glass of cold water into a warmish room to see how multitudinous bubbles of gas form on the inner walls of the vessel. These suggest, at any rate, that there is a good deal of gas mixed up with the water. If this were not the case no animals could breathe under water, for while water is a compound (H_2O) of hydrogen and oxygen, it is not possible for animals to separate the two components in the way plants are able to do with the carbon dioxide (CO_2) mixed in the air or the water. Perfectly pure substances, though often advertised, are very difficult to obtain; they are indeed almost ideal, which led a great investigator to say that "chemistry is the science of substances which do not exist." Traces of impurity in a substance are often of great practical importance; they sometimes influence the properties of the substance in a remarkable way. We quote a sentence from Dr. Mellor's admirable textbook *Modern Inorganic Chemistry* (1920):

> H. Vivian says that $\frac{1}{10000}$ part of antimony will convert the best selected copper into the worst conceivable; Lord Kelvin says that the presence of $\frac{1}{10000}$ part of bismuth in copper would reduce its electrical conductivity so as to be fatal to the success of the submarine cable; and W. R. Roberts Austin says that $\frac{1}{5000}$ part of bismuth in gold would render gold useless, from the point of view of coinage, because the metal would crumble under pressure in the die.

Molecules and Atoms

A mixture can usually be separated into its ingredients by more or less simple mechanical means. A compound cannot be broken up into its components without going beyond simple mechanical methods. We break a piece of salt into finer and finer powder, but each particle of salt-dust remains salt. If we could get hold of a particle which would cease to be salt when we broke it in pieces, that particle would be a molecule of salt, and we should have divided it into groups of constituent atoms—sodium

atoms and chlorine atoms. A lump of salt is built up of a prodigous number of molecules of salt; and each molecule is "a little building, of which the atoms are the bricks."

To return to the elements. An ELEMENT has been defined as a substance whose molecule contains only one kind of atom, but this definition must be modified in relation to the fact that the elements uranium and thorium give rise, as we shall see, to other elements different from themselves. Nevertheless the general idea remains that an element is a unique and homogeneous kind of matter.

When an electric current is passed through water (H_2O) it decomposes it into hydrogen and oxygen. Bubbles of oxygen may be collected at one pole, and bubbles of hydrogen at the other pole. This is a fact. There is a theory—perhaps more than a theory—that free atoms of oxygen travel in one direction and free atoms of hydrogen in the opposite direction through the water. "Ion," the Greek word for a traveller, is the term applied to these particles which travel to the two electrodes during electrolysis. Ions are *travelling atoms,* or *groups of atoms,* which are started on their journey by the dissociation of the electrolyte (say, water), and they are believed to carry opposite charges of electricity. Each molecule that is split up gives rise to two kinds of ions (anions, going to the anode pole, and cations, going to the cathode pole); and these two kinds of ions are furnished with equal and opposite charges. The ion with a positive charge of electricity is attracted to the cathode, or negatively charged electrode, and the ion with the negative charge is attracted to the anode, or positively charged electrode, and each ion will be then relieved of its charge and become an ordinary atom again. The speeds of the migrating ions have been measured, and it seems that the heaviest ions (i.e., with the greatest "atomic" weights) move fastest. It has been supposed that this is due to the more slow-going ions dragging along with them a number of molecules of the solvent.

This is very theoretical, but every one knows the practical

application in silver-plating and the like. A brass spoon, let us say, is immersed by a wire in a solution of a silver salt (say, a solution of silver cyanide in potassium cyanide), and the spoon is the one pole—the cathode. A sheet of silver is the other pole—the anode. A weak electric current is passed through the fluid, and cations of silver are then deposited on the brass spoon, which becomes a silver-plated spoon.

Mr. C. T. Kingzett, in his *Popular Chemical Dictionary,* says of chemical changes:

> All articles of food and clothing; the materials of which our houses and buildings are constructed and which are needed for their decoration or repair; every art and every industry—all depend essentially for their production or activity upon chemical changes as realised in nature or made by man to serve human purposes. The same is true of the production and decay of animals and vegetable matters, as also the process by which they are broken up and the resulting products made available in their turn as food for new life. These chemical changes constitute a sort of adaptation of matter to environment, and in a sense are acts of creation, as every such change produces products which, although related, are quite distinct in character and in properties from the original substances which give rise to them when subjected to the required influences. Thus, in a very literal sense, all matter—which, as will be seen in other places, appears to be essentially one in nature—is actuated by a spirit of life, being susceptible to change when the environment is appropriate.

Chemical Change

Chemistry is concerned with the different kinds of matter in the world and with the changes which they produce by interaction. If a bar of iron is heated it becomes longer, but it returns to its original length when cooled. We call this a *physical* change, for the iron remained iron from first to last. But when a piece of iron

Photo: James's Press Agency.

CAST IRON IS HARD AND BRITTLE AND CANNOT BE WELDED AS WROUGHT IRON, BECAUSE THE FORMER CONTAINS A QUANTITY OF FOREIGN MATERIAL WHILE THE LATTER IS ALMOST PURE METAL

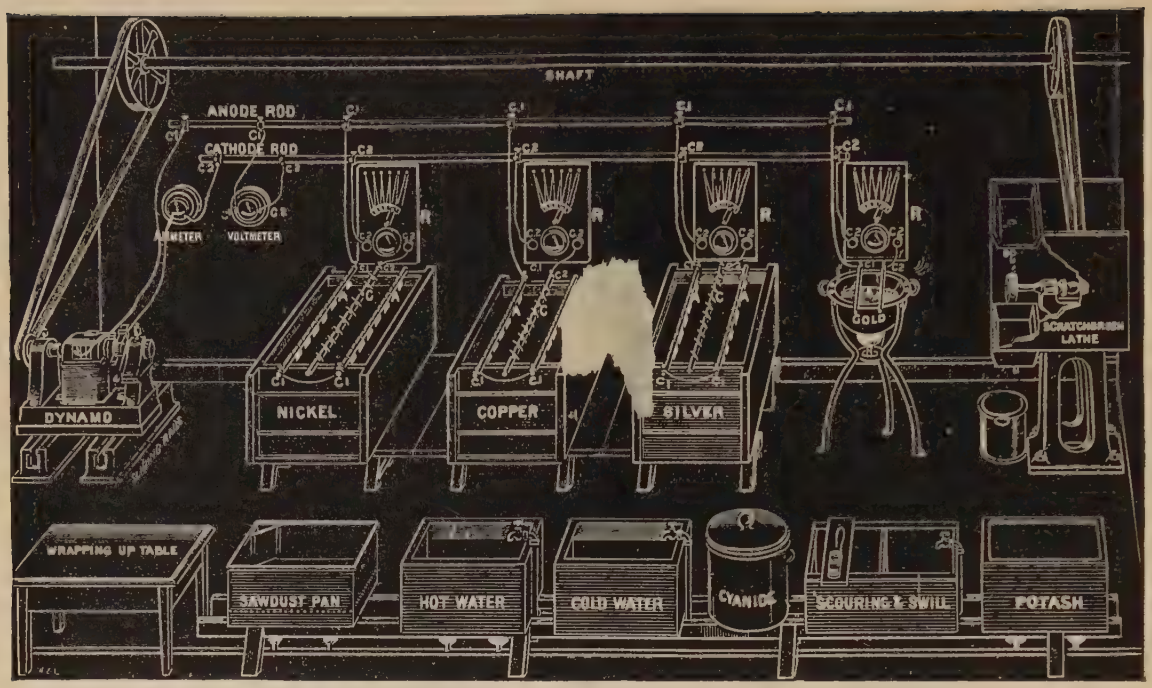


Photo: W. Canning & Co.

DIAGRAM SHOWING ARRANGEMENT AND WIRING OF COMPLETE ELECTRO-PLATING PLANT

In all cases the principle is the same—the electrolysis or decomposition of the dissolved metallic salt and the deposition of ions of the metal—nickel, copper, silver, or gold—at the cathode, namely, on the article. Many articles can be plated at once, and the same electric current may operate in many different baths. The plated articles are eventually burnished.

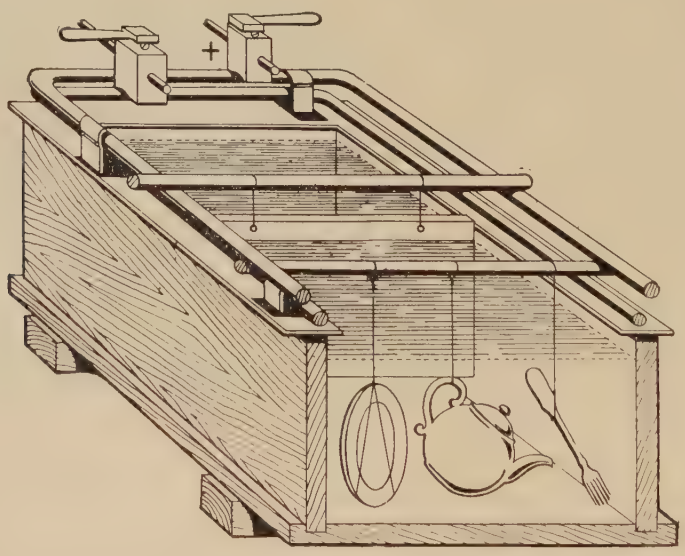


DIAGRAM OF AN ELECTRO-PLATING BATH, SHOWING THE METHOD OF HANGING SMALL ARTICLES IN THE DEPOSITING VAT FOR PLATING

The article to be plated is hung by a wire into a solution of silver salt and forms the *cathode*. A sheet of silver, shown further back, is the *anode*. A weak electric current is sent through the silver solution or electrolyte. The electrolyte is decomposed, and silver (the *cation*) is deposited on the article to be plated. The *anion*, collecting at the anode (the sheet of silver), dissolves more silver so that the strength of the electrolyte is not changed.

left out of doors begins to rust, we call this a *chemical* change, for the iron becomes something different, namely, iron oxide, with quite different properties. This iron rust is not transmuted iron, but iron in combination with oxygen, and that is a very different thing. Chemical changes always imply a shuffling of the cards, a new arrangement of partners. "Pieman + pie," as the American expositor puts it, "on the one side; Boy + penny on the other side." A change occurs, and the situation is "Pieman + penny" and "Boy + pie." This sort of thing is going on ceaselessly all the world over. It is necessary to say, however, that the boundary-line between Chemistry and Physics has become very indefinite, especially in light of the fact that the qualitatively chemical differences between Uranium and Radium or Thorium and Radium seem to depend on quantitatively physical differences in the corpuscles of electricity.

Demonstrating the Invisible

Many of the materials with which the chemist deals are invisible, and so is the air we breathe, as long as it is dry and clean. In ordinary circumstances, none of us ever *sees* oxygen, hydrogen, nitrogen, or carbon dioxide, and yet all these are as real as iron and lead, sulphur and diamonds. As Professor James C. Philip says:

> A gas may be without smell or taste, it may be as intangible as a spirit, and as for seeing it, why, it may be off and away while the observer still thinks he is looking at it.

Now it is worth while pausing to ask how the chemist is so sure about what he cannot see, why he must reject the proverb "seeing is believing."

Invisible materials betray themselves by what they do. The oxygen rusts the iron; the carbon dioxide which we breathe out into a beaker of lime-water makes the water cloudy; a mouse lowered into a shaft containing the deadly carbon monoxide gas is

killed. The danger of this poisonous gas escaping from a leaking or badly burning stove is well known. White mice used to be carried by submarines in order to detect the dangerous CO gas; but there are finer methods now in use.

When a tumbler is inverted into a basin of water, we cannot press it quite down, and we know that the rise of the water is being resisted by the invisible air in the tumbler. Sometimes we can ourselves almost lean up against the rapidly moving invisible air! Still more convincing is the test by which Lavoisier founded modern chemistry—the test of the balance. For every invisible material has its weight, even the hydrogen, which is fourteen and a half times lighter than air, and therefore lifts the balloon so easily. We do not need to go any further in indicating how chemistry demonstrates the invisible, but it would be dull indeed not to refer to the modern demonstration of invisible gases by turning them into liquids or solids.

§ 3

Liquefaction of Gases

Modern science has given us a vivid picture of that condition of matter which we call gaseous. Professor Clerk Maxwell compared the molecules in calm air to a swarm of bees, when every individual bee is flying furiously, first in one direction and then in another, while the swarm, as a whole, either remains at rest, or sails slowly through the air. But we have to add to the picture the collision of one bee with another bee, for a molecule can travel only a short distance (its mean path) without striking another. Indeed, as Clerk Maxwell calculated, the number of collisions which a molecule must undergo in a second must be reckoned by thousands of millions. In his famous discourse on molecules he spoke of the time it took for the smell of an opened bottle of ammonia to pervade the room. The molecules of the ammonia have a velocity of six hundred metres per second, but they are not able to spread at that rate through the room. They strike against the molecules of air and are delayed. "Each molecule of ammonia is so jostled

about by the molecules of air, that it is sometimes going one way and sometimes another, and like a hare, which is always doubling, though it goes at a great pace, it makes very little progress." Gradually, however, the ammonia gas does spread through the air of the room.

In a liquid, as contrasted with a gas, the molecule has hardly any free path, but "is always in a state of close encounter with other molecules." In a solid the molecules have almost lost their opportunities for moving about.

Now everyone knows that water-vapour may condense into flowing water, and that this may freeze into solid ice, which may melt again and steal off as mist. Saturated steam above 720.6° C. is a gas. Thus water occurs in four states. The passage from phase to phase is familiar, but in the liquefaction of gases it became dramatic.

About the beginning of the nineteenth century, Northmore and others liquefied sulphurous acid gas by pressure, but progressive research on the liquefaction of gases began with the work of Faraday and Sir Humphry Davy, in 1823, when chlorine, carbonic acid, ammonia, and other gases were liquefied by great pressure. Later on Thilorier showed how the evaporation of a jet of liquid carbonic acid produces cold so great that the rest of the jet is frozen into fine snow. There is a temperature above which no amount of pressure will produce liquefaction, and it was not until devices for securing very low temperatures were discovered—and this was a great achievement of modern science—that it became possible to liquefy oxygen, nitrogen, and the like. But with the invention of methods of obtaining very low temperature, which brings the molecules close together, just as heat drives them apart, oxygen and nitrogen were conquered, and in 1898 Professor (now Sir James) Dewar produced liquid hydrogen. As Professor Tilden remarks:

> It was both interesting and gratifying that the final victory which crowned the long series of successful attacks

upon the apparently impregnable position of the "permanent gases" should have been recorded in the laboratory of the Royal Institution, where the first successes in this field were won by Faraday.

Transmutation of Elements

The chemists or alchemists of the Middle Ages sought after "the Philosopher's Stone," which would transmute "base metal," such as lead, into gold. Some even believed that their quest was successful, for the science of chemistry was not far enough advanced to dispel their illusions. If a knife-blade be placed in a solution of blue vitriol or sulphate of copper, it comes out like copper; and, as Professor James C. Philip points out, "to the alchemist the result admitted of no other explanation than that the iron had been converted into copper. We know now that no such change takes place: some copper comes out of the solution and is deposited on the surface of the iron, while by way of holding the balance even, an equivalent amount of the iron passes into solution."

The transmutation of one element into another was discredited when the science of chemistry began to get on its feet, and, just as naturalists believed in "the fixity of species," so chemists believed in the immutability of the elements. Each element is itself and no other. But everyone knows the change of view that the discoveries of the twentieth century have brought. It is now established that the element uranium may in part change into radium and some other elements. A spontaneous change occurs, associated with the partial disintegration of the uranium atom, which leads to the formation of minute quantities of radium (apparently with ionium as an intervening link). From another changeful radio-element, namely, thorium, there may also be derived at a very low rate minute quantities of radium. It appears that the uranium and thorium give off particles of helium, an element first detected in the sun and restricted as far as the earth

is concerned to minerals containing the two radio-elements just mentioned. The final product of the metamorphosis appears to be lead, and in this way a radio-active mineral may be utilised as a "geological clock." Professor Soddy explains this:

> In a uranium mineral each 1 per cent. of lead in terms of the quantity of uranium signifies a lapse of a period of 80,000,000 years. Errors, of course, are possible, if lead should have been an original constituent of the mineral, but these are minimised by taking a large number of different minerals. On the other hand, every cubic centimetre by volume of helium per gram of uranium in a uranium mineral signifies 9,000,000 years, and—as here helium, being a gas that forms no compounds, cannot have been initially present, and as, moreover, some will have escaped—the age of the mineral by this method is a minimum, whereas the age by the lead content may be too high. The Carboniferous rocks tested by this new method appear to have an age of some 350,000,000 and the oldest Archæan rocks of over 1,500,000,000 years.

The difficult subject of radio-activity has been referred to in other chapters, but it cannot be more than touched on in a work of this scope. Enough has been said, however, to show that the doctrine of the unchangeableness of the chemical elements requires revision. We have already quoted from Professor Soddy, well known as one of the brilliant pioneers in the study of radio-activity, and we select a summing up sentence:

> The radio-elements are in course of spontaneous transmutation into other elements, and the process proceeds through a long succession of more or less unstable intermediate elements, until the final stable is reached.

In the domain of things this is the nearest analogue to evolution in the realm of organisms.

§ 4

Chemistry of the Living Creature

Of the fourscore and more elements, no fewer than twenty-nine are known to occur in living creatures; but twelve of these

are rare. Those that are always present are hydrogen, carbon, oxygen, nitrogen, phosphorus, sulphur, potassium, magnesium, calcium, and iron, and to these there should probably be added sodium, chlorine, and silicon. Not uncommon are iodine (e.g. in brown seaweeds and the thyroid gland), manganese (a trace in most animals and in some plants), bromine (in brown seaweeds, a trace in some animals), and flourine (in bones and a few plants).

The first big fact is that the elements invariably present in organisms are common in the inorganic world. The second big fact is that the essential and most important elements in living creatures are hydrogen, carbon, oxygen, and nitrogen. In most animal and plant proteins sulphur is also present in addition to the Big Four. In nucleo-proteins, like the chromatin of the nuclei of all cells, there is likewise phosphorus.

As far as the constituent *elements* go, there is nothing peculiar in living matter. On or near the surface of the cooling earth there would be a natural abundance, the chemists tell us, of water and CO_2, and in this triumvirate there is a unique ensemble of fitnesses for forming the stones and mortar of the house of life—unique, for instance, in the synthetic possibilities of carbon, in the solvent power of water, in the stimulating power of oxygen (set free by the dislocation of CO_2), and in the "attractive" capacity of all three—drawing in other elements, such as magnesium and iron, to serve fresh purposes.

It may be of interest to notice individually some of the common elements that occur in living creatures. Hydrogen "ions" are very important in respiration and gastric digestion. Oxygen is a releaser of energy in vital combustion and an attractive agent bringing in other useful elements. Water (H_2O) is the chief constituent (over 70 per cent.) of living matter. Nitrogen combines with carbon, hydrogen, oxygen, and a little sulphur to form proteins, and all living implies the building up and breaking down of proteins. It gives living matter its restless explosiveness, "because it is loath to combine with and easy to dissociate from

Photo: reproduced by courtesy of Merryweather & Sons, London.

A MOTOR FIRE-PUMP WITH CHEMICAL FIRE-ENGINE AND FIRE-ESCAPE

The up-to-date Fire-engine is, of course, motor driven, and it is frequently arranged not only to combine a powerful pump which is driven through the agency of the propelling motor, but also to carry a Fire-escape and a Chemical Fire-engine equipment. In the above illustration the Chemical Engine is fitted immediately behind the driver's seat. The point of this ingenious invention is to charge the projected water with carbonic acid gas. This gas is generated in a closed cylinder by mixing sulphuric acid with water containing bicarbonate of soda in solution, or it is compressed to a high degree in a separate steel cylinder. The water being projected on a fire releases the gas, which, being much heavier than air, lies like a blanket on the burning material, keeps out the oxygen, and quickly subdues the flames. The Chemical Engine can be brought into use immediately the scene of action is reached and will frequently extinguish a fire of ordinary dimensions with a minimum water damage, the powerful pump at the rear of the chassis being available for larger conflagrations.

Photo: J. J. Ward.

NATURE'S TRANSFORMATIONS OF WATER

Here we have the water-vapour of the air falling as frozen snow, then thawed into running water, and again frozen into icicles.

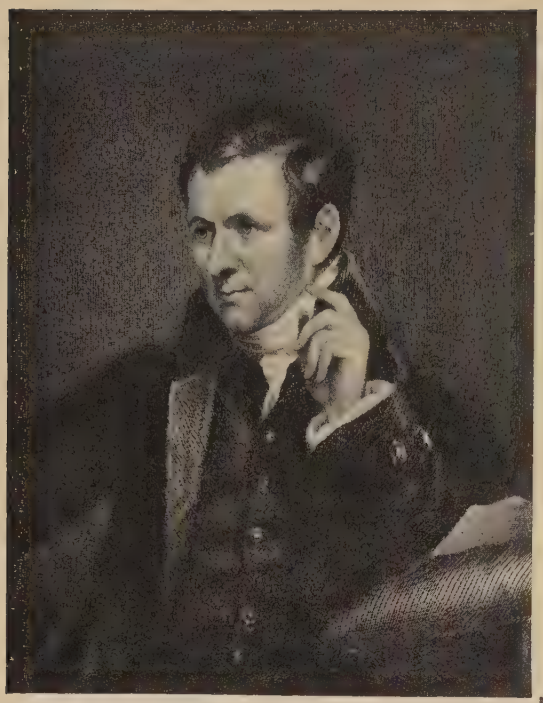


Photo: Rischgitz Collection.

SIR HUMPHRY DAVY (1778–1829).

An illustrious chemist, Professor at the Royal Institution, London, where Faraday was his assistant. His early recognition of "the chemical agencies of electricity" (1806) was of great importance. He discovered potassium, sodium, barium, strontium, calcium, and magnesium. Everyone knows of his invention of a miner's safety-lamp, which has saved many lives.

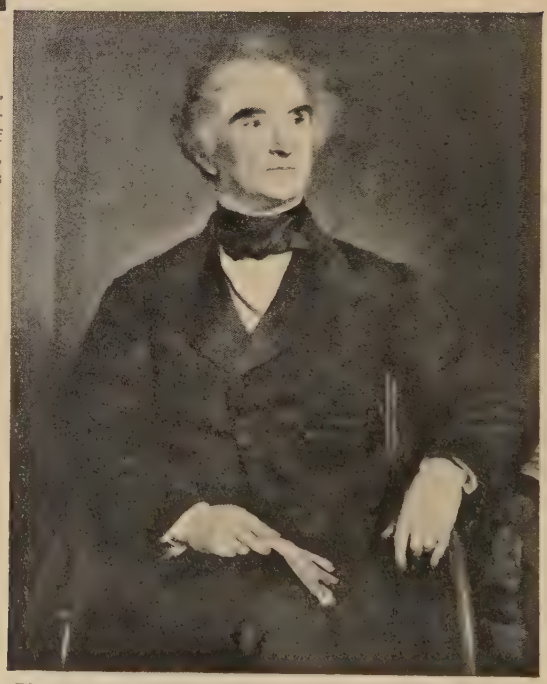


Photo: Rischgitz Collection.

JUSTUS VON LIEBIG (1803–1873).

One of the greatest of chemists, famous for his foundation of Agricultural Chemistry, his contributions to Animal Physiology, and his discoveries in Organic Chemistry. He made clear the general idea of the Circulation of Matter. He had a strong practical sense, and everyone knows Liebig's "beef-extract." He did a great deal towards the technical equipment of chemical laboratories.

most other elements." Carbon is unique in its capacity for forming compounds, of which more than a hundred thousand are known, and its combination with oxygen (CO_2) affords the source from which most of the free oxygen of the air is derived.

The Remarkable Power of Carbon

The Chemistry of Carbon is of a peculiarly interesting nature; because of its remarkable power of uniting with itself as well as with other elements it is enabled "to build up single molecules containing very large numbers of atoms, and such molecules form the basis for framing the structure of living organisms. Without these two properties of the carbon atom, life, at least as it is known upon the earth, would be impossible." It is this element, in combination with a few other elements, for instance, hydrogen, oxygen, and nitrogen, which gives rise to a multitude of compounds of every degree of complexity, and out of which many substances are produced which are essential in building up the bodies of animals and plants.

As we have seen, living products are chiefly based on four elements—carbon, nitrogen, oxygen, hydrogen. From these four elements, with admixtures, most substances of the living world are made up.

> It is a curious fact that all life on the earth should depend on two single factors, (1) the presence of a mere trace, lying at the level of only between three and four parts per 10,000 of this gas (carbon-dioxide) in the air, and (2) the natural power of the carbon atom contained in the carbon-dioxide, of entering into energy relationships with fellow carbon atoms. Given these conditions, a suitable form of energy and a suitable transformer for that energy, capable of turning it into chemical energy of carbon compounds, and it follows that all the complex constituents which form the basis of life not only can, but must arise.[1]

[1] Benjamin Moore, *Origin and Nature of Life.*

As we have seen in a previous chapter, the energy transformer is the green plant-cell aided by the green colouring matter, called chlorophyll, which it contains.

It is interesting to note that carbon exists on earth in different forms; there are three modifications of it to be found, all very different in outward appearance, and it may be added, of different values in human estimation. We have carbon in the black and opaque form of charcoal, and as graphite or common black-lead, and in the transparent crystalline form of a brilliant diamond. All these things are merely different forms of the same "stuff." And yet, although successful efforts have been made to manufacture artificial diamonds, it has not been found possible to do so on a commercial basis, that is to say, it is still cheaper to procure them by expensive means from the natural resources than to manufacture them in the laboratory.

The Regulation of Vital Phenomena

Sulphur in small quantity is an essential part of the C-H-O-N-S compounds called proteins. Phosphorus is necessary for the formation of chromatin, which is so important as a vehicle of hereditary characters; it is essential in the formation of tissues so different as bone and brain.

Potassium is the most active of metals biologically considered, and its salts play an important part in the regulation of vital phenomena. Magnesium is an essential constituent of chlorophyll, in the making of which iron is also necessary though not included in its composition. Iron also occurs in the red pigment of the blood which captures oxygen from the outer world. Calcium compounds play an important part in stimulating or slowing vital processes. So we might continue, but we have said enough to suggest the manifold ways in which the various qualities of elements are utilised in the service of life.

§ 5

Circulation of Matter

One of the epoch-making ideas in science is that of *the circulation of matter*—a corollary of the idea of conservation. It is an old idea, for one of the Greek philosophers, Heraclitus, is responsible for the epigram "All things flow"; but its demonstration belongs to the nineteenth century. Just as we associate the name of William Harvey with the circulation of the blood, so we should link the name of Justus Liebig (1803-1873) with vivifying the fact of the circulation of matter. Many people know the name of this great chemist in connection with beef-tea, but he has greater claims for commemoration.

Everyone knows how the clouds condense on the cold rocks of the mountains, how the drops of water flow together into runlets, how they fill up the bog-moss sponges and overflow into streamlets, how these make rivers which join the sea, how the sun-drawn mist rises from the ocean and forms the clouds which break on the mountain-side. So the world goes round. But this is far too simple a case, for we have been dealing with water from beginning to end. Let us take a better case.

Circulation of Nitrogen

All living matter includes the nitrogenous carbon compounds called proteins, such as white-of-egg and the gluten of bread. In other words, all living creatures require nitrogenous supplies. Animals obtain these by eating other animals or by eating plants; so we may leave them, for the moment, out of account as far as the problem of nitrogen-supply is concerned. The question is where plants obtain nitrogen, and the generally valid answer is that the roots absorb nitrates and the like from the soil. There is abundance of nitrogen in the air—indeed, four-fifths of the atmosphere is nitrogen—but this treasure-house is closed to plants, except in the case of sundry types which, with the help of partner-bacteria (see Sir Ray Lankester's article Bacteria), are able to capture

the nitrogen in the air which the rain brings down into the soil within reach of the rootlets. (See the article on BOTANY.)

Leaving the exceptional cases aside, we see that plants depend on nitrogen compounds in the soil. Where do these come from? Electrical discharges in the atmosphere lead to the formation of nitric acid and nitrite of ammonia, which the rain brings into the soil. Various soil-bacteria help to change nitrites into the more useful nitrates, on which plants largely depend; but it must be admitted that other soil-bacteria (which cannot be credited with philanthropy) work in the opposite direction. But when we pass from extrinsic supplies of available nitrogen such as thunderstorms and Leguminous plants may afford, we face the fact that one cosmic generation lives on the graveyards of its predecessors. The bread we enjoy is a rehabilitation of the guano deposited by the birds of ancient sea-cliffs.

What we have just begun to do in illustrating the circulation of matter may be readily elaborated, and the idea may be extended to other elements. It should be kept in mind, however, that only a few elements share in the main circulation, for only about a dozen are always represented in living creatures and a not much larger number makes up 99 per cent. of the earth's crust. But in an Outline like this the important thing is to make clear some of the germinal ideas of the science, and this is one, that many of the elements of the chemical world often change their partners in their unending dance.

Catalysts

When we turn from a chemical treatise of a generation ago to one of to-day the whole atmosphere seems to be different, and one of the changes is suggested by the word *catalysis,* still unfamiliar to many. What does it mean?

> There exist certain substances [says Professor R. K. Duncan] which may lie in a vessel seemingly inert, and yet *by their mere presence may dictate what actions shall or shall*

> *not take place.* A thing which has this commanding power is a *catalyst,* and the process is *catalysis.*

The peculiar feature is that the substance which exerts a catalytic influence is not affected by what it does; it can be used over and over again. The presence of a very small quantity of platinum causes the combination of large quantities of oxygen and hydrogen, but it is not exhausted in the process. Prof. Duncan gives a good example.

> Chromic chloride is a curious substance that exists in two forms, soluble and insoluble. The "insoluble" violet crystals may be left under water for days unaffected; but drop into the test-tube a trace of chromous chloride, even 0.000025 of a gram, and the violet crystals hasten to bury themselves in the water, the temperature rises, and an indigo-blue liquid results. The mere presence of a trace of the catalyst has suddenly let loose the powerful affinities lying latent in the violet crystals, and the substance is dissolved. It is almost as curious as though a pound of salt thrown off the Battery should dissolve Manhattan Island. This is an example of what is called physical catalysis, for the chemical properties of the chromic chloride are the same after as before; it has simply passed into solution.

Ferments

To be included among catalytic substances, yet conveniently separated, are the ferments or enzymes produced by living creatures (e.g. yeast plant and bacteria) or by living cells like those of the digestive glands. The fact that the yeast cell, the diameter of which is only one three-thousandth part of an inch, is capable of so many chemical changes is one of the unexplained wonders of the world. As in the case of inorganic catalysts, so with these organic ferments, minute quantities can bring about chemical transformations of great magnitude and at a very rapid rate. The number of ferments is legion and they work like magic; quickly and quietly they bring about changes which in the laboratory

would require powerful reagents and high temperature. They are not living, but they are essential to life; they are always in a "colloidal" state, and they effect many different kinds of change, though each usually does only one thing. They help in building up and in breaking down. The changes they bring about take place most rapidly at a certain optimum temperature, and the ferments are susceptible to the influence of other substances, such as salts; some always work in couples.

As examples of organic ferments we may mention the ptyalin of the saliva that changes starch into sugar, the pepsin of the stomach that changes protein into peptone, the trypsin of the pancreas, and the diastase of the green leaf that alters the solid starch into fluid transportable sugar. We know what these organic ferments are able to do; but we do not know what they are. Indeed, there are so many unsolved problems before the investigator of ferments, that the darkness seems almost greater than the light. Facts are rapidly increasing, but a rationale of the facts eludes us.

§ 6

Crystals

We have spoken of crystals; little is known of the determining cause of the formation of crystals, and the subject is too complicated a one to be dealt with in this work. The science of crystals is concerned with the study of the definite geometrical forms assumed by elements and compounds under certain conditions. The structure of a crystal consists of a small group of atoms which assume a regular arrangement in a fixed pattern. For instance, in a crystal of rock-salt, which is built up of sodium and chlorine atoms, each sodium atom has six chlorine neighbours, and each chlorine atom six sodium neighbours, arranged in a manner typical of rock-salt crystals. The atomic distance of these is about one hundred-millionth part of an inch.

Many chemical bodies assume the crystalline state when they

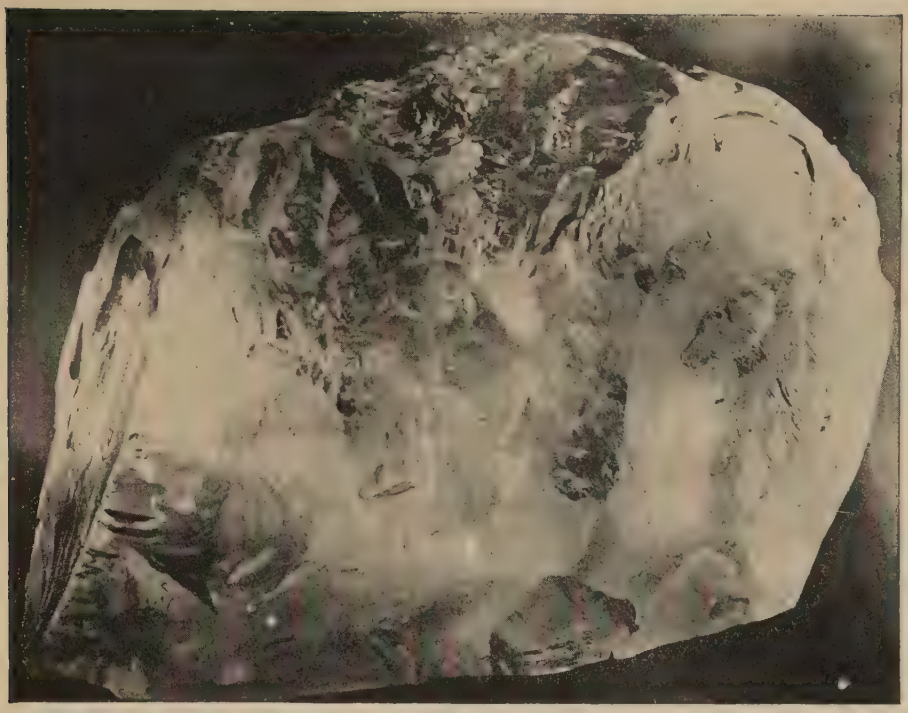


Photo: James's Press Agency.

"THE CULLINAN DIAMOND"

The largest diamond in the world, found in South Africa in 1905. Before it was cut it weighed a pound and a half, and was about as large as the illustration. In the rough state it resembled a piece of ice rather than a superb diamond. A diamond is the purest form of crystallised carbon.

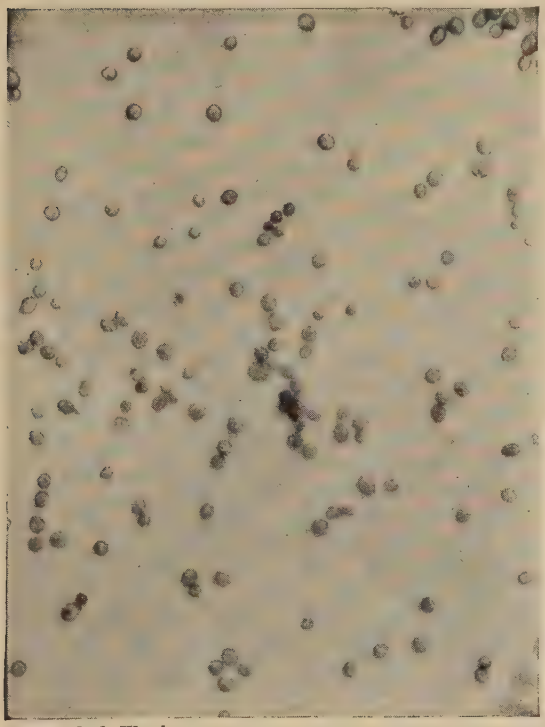


Photo: J. J. Ward.

THE YEAST PLANT (SACCHAROMYCES)

The yeast-cell produces a ferment which changes sugar into alcohol and carbon dioxide: or attacks the dough and not only "raises" it by evolving the gas, but makes the bread more palatable and digestible, producing likewise a trace of alcohol. There are several different kinds, e.g. the common cultivated yeast of beer and bread, and the wine-yeast found wild on the skin of grapes or in the vineyard soil. It was Pasteur who *proved* that the yeast plant is the cause of the kinds of fermentation referred to. Each ellipsoidal cell is a tiny, colourless plant able to bud out others just like itself. In actual size each

Photo: J. J. Ward.

THE WINE-YEAST OR "CALIFORNIAN BEES"

This so-called "Ginger-beer Plant" consists of various micro-organisms, two of which, a yeast (*Saccharomyces pyroformis*) and a bacterium (*Bacterium vermiforme*), set up an alcoholic fermentation in a sugar solution.

Photo: Rischgitz Collection.

MENDELEEFF

The celebrated Russian chemist (1834–1907), whose name will be always associated with the establishment of the Periodic Law, disclosing the relationships of the chemical elements. He greatly enriched the whole science of chemistry, especially where it joins hands with physics.

Photo: Russell & Sons, Southsea.

THE LATE PROFESSOR SIR WILLIAM RAMSAY, K.C.B.

One of the most distinguished of modern chemists, especially in the department of Physical Chemistry. He isolated Argon, Helium, and three other inert gases from the air, and conducted some remarkable experiments in connection with radio-active elements. No man since Davy has made in chemistry discoveries of such a fundamental and far-reaching character.

change from liquid or gaseous condition into the solid form; they may be produced, for instance, by the evaporation of saturated solutions. It has been stated as a statistical truth that "everything strives towards symmetry in so far as the environment will allow."

Diamonds

A large number of definite chemical bodies are found in nature in crystalline conditions, such as the diamond. The diamond is the purest form of crystallised carbon. In the diamond "every carbon atom is symmetrically surrounded by four other carbon atoms, arranged at the corners of a tetrahedron in such manner that the whole crystal is one continuous molecule, thus explaining, as it is thought, its great density and hardness."

A crystal arouses our interest by reason of the regularity of its form, the perfection of its surfaces and angles, its transparency and brilliancy. A perfect crystal, like a diamond, is quite transparent and colourless, although it possesses that marvellous "fire" which we see oscillating with every movement, but most precious stones are tinged with grey, yellow, or brown. It is due to the high qualities of refraction and dispersion of light that diamonds give off the beautiful flashes of blue, gold, and red "fire"; other colours such as ruby red and emerald green are more rare. The colour of many precious stones is really produced by minute proportions of impurity. The continued study of the formation of crystals, it is thought, may throw further light upon electrons and their connection with the structure of the atom.

Colloids

Another set of facts of first rate importance relates to what is called the colloidal state of matter. In 1861 the Scottish chemist Thomas Graham noticed that some substances pass readily through a parchment paper, while others diffuse very slowly through. He called the latter "colloids" (from the Greek *kolle* =glue) and the former "crystalloids." White of egg and gum may illustrate colloids; sugar and salts crystalloids. But as many

substances can exist *as both,* it is better to speak of the colloidal and crystalloid conditions of matter. Moreover, the colloidal condition may be fluid, and then it is called a "sol"; or it may be gelatinous (even solid), and then it is called a "gel." In any case, "matter in the colloidal state is in the form of ultra-microscopic particles of solid, or droplets of fluid, in suspension or in other manner of dispersion, in another solid, liquid, or gas." The study of the properties of the colloidal state has proved of great importance in chemistry, and it is of fundamental interest to the physiologist, for living matter is in a colloidal state, Professor Bayliss writes:

> Protoplasm in the living state has the properties of a liquid system, containing, however, particles of solids and droplets of immiscible liquids in a freely movable state.

Many vital phenomena are bound up with the colloidal properties of the physical basis of life.

We have said that many of the rare elements, though very important to us, lurk quietly in remote corners.

Rare Earths and their Uses

Iron is common, but gold is comparatively rare. To get two ounces of the metal gallium a great chemist had to work over nearly 600 pounds of crude material, but aluminium is easily procured. Why are half of the known elements so rare that few people know their names? As Professor R. K. Duncan writes,

> Who, for example, has ever heard of, much less worked with, lanthanum, europium, erbium, neodynium, gadolinium, thulium, praseodymium, terbium, ytterbium, samarium, holmium, tantalum? Yet these forbidding names represent certain elements of matter just as do others, such as sulphur, phosphorus, or lead; elements, too, unique in their properties and filled with all kinds of potential usefulness to man.

We cannot answer this plain question: Why are many of the elements so rare? It may be that they are rare because they are

always changing into something else; or it may be that they are being made from other elements which are also rare. A significant fact is that the dozen rare elements mentioned above are found associated together as if they formed a family party.

Let us pass to something easier—man's use of some of the rarities. Towards the end of the nineteenth century, Carl von Welsbach hit upon the brilliant idea of increasing the incandescence of a gas flame by making it heat up a cotton mantle impregnated with a rare element, such as lanthanum. Various improvements followed, but the principle remains the same today. The cotton mantle was replaced by a fabric made of china-grass, and the lanthanum was replaced by 99 per cent. thoria and 1 per cent. of ceria—two rare earths which work into one another's hands in some rather mysterious way. The theory is obscure; the practical result is brilliant light.

In 1897 Professor Nernst of Göttingen showed that a filament made of rare earths (thoria or zirconia) was at ordinary temperatures a non-conductor of electricity, but a very good one when heated—even when "lighted by a match." So we got the Nernst electric lamp, which gives a far finer light than the ordinary carbon filament electric lamp, but has the disadvantage of various complications and delicacies. Other rare elements have been tried, each with its own virtues. Thus there is a lamp with a filament of the very rare osmium, "probably the most refractory and unalterable solid known to science," and therefore furnishing a filament with a very long life. There is another with a filament of the unrustable, steel-hard, element called tantalum, which occurs in South Dakota and in Australia, as part of the mineral called columbite. Still more recent, and also very efficient, is the lamp with filaments of the rare metal tungsten. It must be noted that there are many effective lamps, such as the carbon-lamp, which do not use rare earths; but it is of interest to realise that some of the rarities among the elements are common in the lamps of our houses and streets, and that academic curiosities have be-

come of everyday practical utility. But man has not been able to devise a light as economical as that of the fire-fly!

And yet we cannot pass from this subject without some appreciation of the progress that man has made in the art of producing light. It is a sort of index of his ascent. This was well expressed, *for the time,* by Sir William Crookes's preface to the first edition of Faraday's *Chemical History of a Candle.*

> From the primitive pine torch to the paraffin candle, how wide an interval! between them how vast a contrast! The means adopted by man to illuminate his home at night stamps at once his position in the scale of civilisation. The fluid bitumen of the Far East, blazing in rude vessels of baked earth; the Etruscan lamp, exquisite in form, yet ill adapted to its office; the whale, seal, or bear fat, filling the hut of the Esquimau or Lapp with odour rather than light; the huge wax candle on the glittering altar; the range of gas lamps in our streets—all have their stories to tell. All, if they could speak (and after their own manner they can) might warm our hearts in telling how they have ministered to man's comfort, love of home, toil, and devotion.

This was well said, but we have had a glimpse of what might be added thereto—of incandescent mantles made of rare elements gathered, often laboriously, from the far corners of the earth; of delicate metal filaments whose toughness is such that the resistance they offer to the passage of electricity produces a most excellent brilliance; and of subtleties on the inventor's horizon which promise still more perfect light.

A Story about Helium

The element helium was first detected in the sun by means of the spectroscope. It was twenty-five years later before it was recognised upon the earth. How important and unlooked-for results may follow from scientific investigations and discoveries is illustrated in this case, as in many others.

Helium is chemically inert; like argon it unites with no other

chemical element, it is wholly indifferent to them all. This means that helium cannot be burned. In this connection a curious story is told. It is the next lightest gas to hydrogen, and unlike hydrogen it is non-inflammable. In the late war the belligerents anxiously searched for a gas to fill airships which would be light and *non-inflammable.* The great drawback to the German Zeppelins was that they were filled with the highly inflammable hydrogen. The Allies made a discovery, thanks to a wide-awake enthusiast who suggested helium, but helium was enormously expensive to produce. However, there are in Texas certain gas wells which yield helium. Large plants were constructed with haste to recover helium from the natural gas by means of liquefaction, with successful results. Mr. C. G. Abbot tells the sequel:

> The matter was, however, kept a well-guarded secret. Even the name was hidden. Photographs of the plant taken were labelled "argon" manufactories. The idea was spread that the purpose of the experiments was to produce a new variety of poisonous gas for warfare, or perhaps a special variety of gasoline for use in airplanes. All sorts of camouflage were adopted to prevent the enemy from learning the true purpose of the experiments. So far had the work progressed that at the time the Armistice was signed a consignment of 150,000 cubic feet of helium was on the dock at New York, waiting to be sent to France to be used by the Allies for their balloons. Plans were on foot for increasing the output of helium enormously, so that it is probable that had the war lasted until the summer of 1919 the Allies could have employed helium gas for observation balloons and for Zeppelins with entire immunity from all possibility that they could be shot down with incendiary bullets.

This may serve as a final diagrammatic instance of the endless ways—ever increasing in subtlety—in which the chemical world intersects that of human life, both in its heights and in its depths.

BIBLIOGRAPHY

Duncan, R. K., *The New Knowledge* (1906) and *The Chemistry of Commerce.*
Fischer, Emil, *Chemical Research and National Welfare.*
Meldola, Raphael, *Chemistry* (Home University Library).
Mellor, J. W., *Modern Inorganic Chemistry.*
Ostwald, W., *Introduction to Chemistry.*
Philip, James C., *The Wonders of Modern Chemistry.*
Soddy, Frederick, *Matter and Energy* (Home University Library).

XXII

THE CHEMIST AS CREATOR

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MODERN Chemistry practically dates from the time when the burning fire became intelligible—when the great French savant Lavoisier made it clear that a burning substance unites with oxygen from the air and gives off an acid—carbonic-acid gas. He proved with his fine balance that the increase in the weight of the substance burned corresponded to the loss in weight in the surrounding air. This does not sound very exciting nowadays, but it was epoch-making. For Lavoisier realised that in all chemical operations it is only the *kind* of matter that is changed, the *quantity* remaining the same.

The Conservation of Matter

This was the discovery of the CONSERVATION OF MATTER, one of the foundation stones of chemistry, and not only a foundation stone, but a touchstone of accuracy, for it was henceforth certain that in every chemical operation the accounts *must* balance. The total mass of the substances taking part in any chemical operation remains constant, no matter what kaleidoscopic transformations may be effected. Since the masses of bodies are at any one place exactly proportional to their weights, the fundamental idea may read that in any series of chemical operations the weight at the end must equal the weight at the beginning. When Lavoisier made one of his famous experiments of passing water-vapour over red-hot iron turnings, and collecting the hydrogen which was thus produced from the water, he weighed everything—the water to begin with, the iron turnings before and after,

and the hydrogen gas as the issue. And his accounts balanced. Nowadays we are so sure that the accounts must balance, that if they do not, then we must discredit the experiment. The solid ice becomes running water, which is caught up into the air as mist, which may become rain on the cold surface of the mountains; but, in all the protean changes, there is neither creation nor destruction. We can neither create nor destroy the smallest particle; the elements which enter into the composition of the soap-bubble film are as lasting as those which form the granite rocks. Nothing can go lost, that is certain!

At the entrance of a great Exhibition there is usually a change-office, which is the seat of busy operations throughout the day. Sometimes a visitor comes with a one pound note, which is not acceptable at the turnstile, and asks for "small money"; sometimes a tramway-conductor comes with 120 pennies, and begs for something lighter; and there are all sorts of operations. But if the change-office is fortunate enough to have perfectly accurate operators, it will not make anything or lose anything all the live-long day. The form of the money is continually changing, but the amount of the money remains always the same. So must it be in all chemical operations. There cannot be anything massive or quantitative in the end which was not there in the beginning, nor anything in the beginning which has not its precise quantitative counterpart in the end. *How, then, can we think of the chemist as creative?*

Constancy in the Properties of Elements

But we must go a step further. There is a remarkable stability in the properties of things. There are chemical elements in unthinkably distant stars, so the spectroscope tells us, which are the same as those on our own earth. Moreover, as the spectroscope continues to tell us, the properties of these elements remain the same, whether here or there. A molecule of hydrogen in the dog-star Sirius seems to behave just like a molecule of hydrogen

LAVOISIER'S EXPERIMENTS ON RESPIRATION. MADAME LAVOISIER AT THE TABLE TAKING NOTES

Lavoisier (1743–94), the founder of modern chemistry by his demonstration of the conversation of matter. In chemical processes of all sorts there are changes in the quality of the matter, but never any change in its total quantity. He explained what breathing really means—the taking in of oxygen to keep combustion or oxidation agoing, and the getting rid of the waste-product carbonic acid gas. He was guillotined in the Reign of Terror, the mob saying, "The Republic has no need of savants."

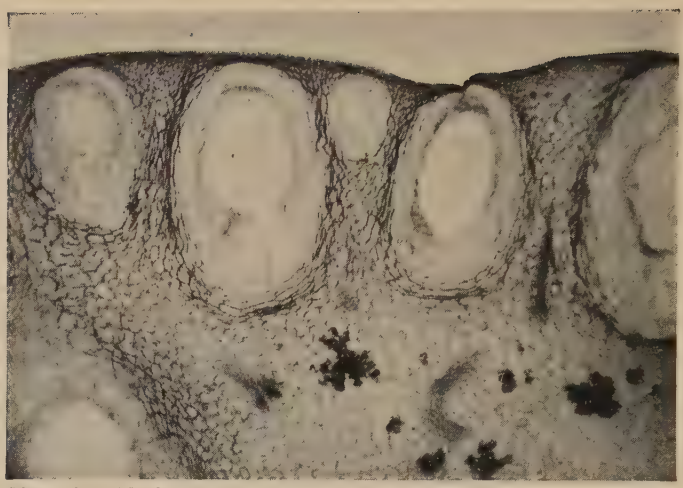
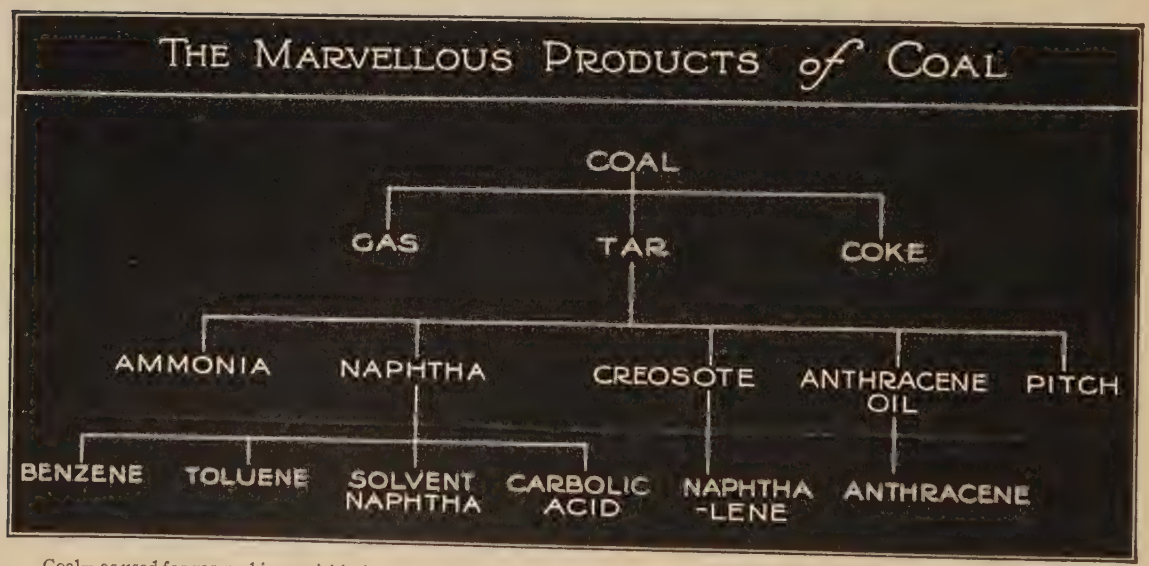


Photo: J. J. Ward.

NATURE'S CHEMISTRY

Section through rind of orange, showing oil glands—which produce the "oil of orange." Fats and oils of a vegetable origin are obtained largely from fruits and seeds. The fruit of the olive-tree contains about half its weight of oil, which is used in packing sardines; in the seed of the flax plant there is over 30 per cent. of oil—linseed oil. It is one of the triumphs of modern chemistry to make *artificial reproductions* of natural oils, e.g. of oil of wintergreen; or to make an *imitation product*, e.g. "oil of mirbane" for the natural oil of bitter almonds.



Coal—as used for gas-making—yields, in addition to gas, watery ammoniacal liquor and tar which pass over in a vaporous condition and are condensed, leaving coke in the retorts.

The coal tar is afterwards distilled and yields an average per ton of approximately 5 gallons ammoniacal liquor, 6 gallons crude naphtha, 26 gallons light oil, 17 gallons creosote oil, 38 gallons anthracene oils, and 12 cwt. pitch left behind in the retorts. It is from these primary distillates of coal tar that so many explosives, drugs, dyes, and disinfectants are produced.

The pitch left in the retorts is equal to about 60 per cent. of the whole tar, which is said to contain in all some 200 different compounds. Anthracene (see above) is used in the manufacture of aniline colours, which, used as dyes, are of great value in the textile and other industries.—From Kingzett's *Chemical Dictionary*.

in a London laboratory. The furniture of the earth and of the heavens may change from style to style, but the fundamental properties of its constituents remain. This conclusion requires careful handling in view of the disintegration of the atom in radioactive substances (see the article FOUNDATIONS OF THE UNIVERSE), but, on the whole, there remains validity in what Professor Clerk Maxwell said in his famous *Discourse on Molecules* (1873):

> Though in the course of ages catastrophes have occurred and may yet occur in the heavens, though ancient systems may be dissolved and new systems evolved out of their ruins, the molecules [a modern chemist would say "atoms"] out of which these systems are built—the foundation-stones of the material universe—remain unbroken and unworn. They continue this day as they were created—perfect in number and measure and weight.

In the face of this how can we speak of the chemist as creator?

Making Vital Products Artificially

The first reason for calling the chemist *creative* is to be found in the fact that he has been able to build up artificially what used to be regarded as exclusively vital productions. This is called "chemical synthesis," and its development forms one of the most interesting chapters in the history of science.

The beginning of the triumphant progress was in 1828, when Wöhler discovered that the salt known as ammonium cyanate changes spontaneously (when its solution is evaporated) into urea. Why should that be important? The reason was this. Urea is a nitrogenous waste product formed by mammals, and filtered out of the body in the urine. Like other products of the living body, urea was regarded as a characteristic vital product. But cyanate of ammonia can be made apart from living creatures, and yet it readily changes into urea. This was the thin end of the wedge. The substances made by living creatures could no longer be kept on a platform by themselves; Wöhler's experiment

showed that one of them at least could arise apart from life altogether. And just about the same time (1826-1828), another pioneer, Henry Hennell, was able to build up alcohol from a simpler carbon compound, ethylene. What was regarded as the yeast plant's exclusive prerogative was attained along a different path, without any living organism at all. It is true that neither of these important steps received due attention: Wöhler and Hennell were before their time; but they head the illustrious list of synthetic chemists.

Outdoing Nature

Indigo, much used in dyeing, and formerly obtained from the indigo plant, is now made artificially, and the same is true of Turkey Red dye, which used to be obtained from the roots of the madder. Vanillin, much used in confectionery, was formerly obtained altogether from the Vanilla plant; but it is now made in large quantities artificially. Oil of winter-green, used in medicine, was formerly obtained from the plant called Pyrola, whch grows in shady woods; but it is now made artificially. The sepia which painters used to employ for sombre pictures was obtained from the inkbag of Sepia and other cuttlefishes, a bag of waste-products which these big-brained creatures eject into the water to cloak their retreat from their enemies. But if a modern painter uses sepia, it is an artificially built-up pigment: it does not come from the cuttlefish. So we might continue through a long list; there has been an artificial synthesis of sugar, of caffein, of salicylic acid, and scores of other complex substances. The list grows every year. The chemist outdoes Nature!

There are two points of great interest here—the first theoretical, the second practical. The interesting theoretical point is that the artificial production of a certain organic compound does not usually correspond to the natural production of the same substance. Thus the artificial production may require great heat, which is out of the question in a plant or an animal.

Photo: J. J. Ward.

DYES FROM SHELLS OF THE SEA-SNAILS (MUREX)

There are many different kinds, but there were two Mediterranean forms in particular that used to furnish the Tyrian purple dye. The smaller shells were pounded; from the larger ones the animal was pulled out and crushed. Great heaps of the shells *Murex trunculus* are still to be found on the Tyrian shore.

GATHERING JASMINE NEAR GRASSE (ALPES-MARITIMES)

The quaint picturesque town of Grasse in the South of France is the chief centre of perfumes manufacture. At Bruno Court's establishment in the spring flower season about 250,000 lb. of roses are received each month. On an average, Bruno's make use of 1,860 tons of orange-blossom, about 1,000 tons of roses, 150 tons of violets, and 130 tons of jasmine. The area of flower farms for perfumery is 115,000 acres. Fat, grease, or oil takes part in the delicate process of making perfumes. But artificially constructed perfumes, with nothing to do with roses, may be used to eke out natural perfumes, or as substitutes for them. The question is whether they smell as sweet.

We take a walk in a wood in Spring and pull a few of the clover-like leaves of the Wood-Sorrel (whose technical name is worth recording, *Oxalis acetosella*); we taste these beautiful leaves, almost as beautiful as the pendent translucent white flower-bells, we enjoy the pleasant oxalate taste (like the "acid drops" of our childhood), due to the salts formed in the course of the chemical routine of the Wood-Sorrel's life. How these pleasant oxalate salts arose in the Wood-Sorrel's leaves is not our question just now, except to this extent, that they certainly were not formed in the same way as the synthetic chemist—the magician of his craft—builds up oxalates in his laboratory.

The second point is strictly practical. If living plants make indigo and living animals make sepia, why should man be so proud of an artificial imitation, which means an ousting of natural production? The answer is not always easy, but it is clear in cases where the chemist can manufacture large quantities of a valuable material without great expense. Thus he has been able to build up the potent substance called adrenalin, used in stopping bleeding and for other purposes—a substance which is produced only in very small quantities by the suprarenal capsules of animals. It is one of the important "internal secretions" or hormones which are discussed elsewhere. To obtain adequate supplies of adrenalin for medical purposes would mean killing a large number of animals. How much more economical when the synthetic chemist can build up this precious substance from simple constituents! In so doing he is a *creator*.

Coal-tar Colours

The chemists have not been content to imitate Nature, they have gone one better—they have made new things, and fine illustrations of this may be found in the story of coal-tar products. Everyone knows that when coal is used to make gas, there is a residue of useful coke and of coal-tar. This strong-smelling, dark-coloured coal-tar used to be regarded as a troublesome by-

product; it is now known to be a sort of treasure-house of dyes and drugs, of perfumes and explosives. It has been called one of the most useful substances in the world.

The reasonable question at once arises, why should coal-tar be such a treasury—"a magic purse of Fortunatus," as Dr. Slosson says? The answer is twofold: (*a*) that coal-tar is a mixture of organic substances which were built up in the ancient club-moss and horsetail forests, the remains of which formed the coal deposits, and (*b*) because the chemist can juggle with the primary products so as to build up quite new artificial ones. When the coal-tar obtained from the distillation of coal is re-distilled, it yields materials like carbolic acid (phenol), so much used as a disinfectant, like naphthalene, used in driving moths away from furs, like benzine or benzol, and so on. The residue left after about ten colourless liquids or white solids have been separated off is the familiar black pitch.

§ 1

The chemist's unit is a molecule, the smallest amount of an element that can exist separately, and he is accustomed to picture the molecule as composed of atoms linked together by hands or bonds. Thus the molecule of hydrogen (H_2) may be pictured as H—H, each atom having one hand. The atom of carbon is pictured as if it had four hands —C—, and thus the symbol of the simplest hydrocarbon (marsh gas) is

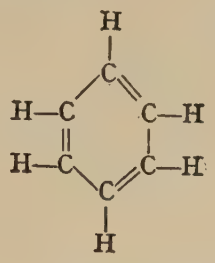
$$\begin{array}{c} H \\ | \\ H—C—H \\ | \\ H \end{array}$$

, or CH_4. Now the coal-tar product called benzene (benzine is a different thing altogether) has the puzzling formula C_6H_6, puzzling because it is not easy to see how the six four-handed atoms of carbon can be "satisfied" with six one-handed atoms of hydrogen. The puzzle

By permission of the British Aluminium Co., Ltd.

Aluminium is extensively used in the construction of many articles, such as motor-car castings and bodywork, cooking utensils, etc. It is chiefly manufactured from the mineral known as bauxite, chemically treated to give alumina, which is subjected to electrical treatment with cryolite as a flux. From the alumina the aluminium is produced. The power used for generating the electric current (by dynamos) is that of falling water. The above illustration shows a six-pipe water track each of which is 39 inches in diameter, the whole length being over one mile. The water-power is utilised to drive the dynamos at the great aluminium works at Kinlochleven in Argyllshire.

was solved by the German chemist Kékule, who saw that the symbol of the benzene molecule should be like a ring or hexagon, in which the carbon atoms are linked together. while the hydrogen atoms hold on to the outside hands.



To explain the importance of this, we quote a paragraph from Dr. Edwin E. Slosson's *Creative Chemistry* (1921)—a brilliantly successful popular exposition of chemical synthesis.

> We need not suppose that the benzene molecule if we could see it would look anything like this diagram of it, but the theory works and that is all the scientist asks of any theory. By its use thousands of new compounds have been constructed which have proved of inestimable value to man. The modern chemist is not a discoverer, he is an inventor. He sits down at his desk and draws a "Kekulé ring" or rather hexagon. Then he rubs out an H and hooks a nitro group (NO_2) on to the carbon in place of it; next he rubs out the O_2 of the nitro group and puts in H_2; then he hitches on such other elements, or carbon chains and rings, as he likes. He works like an architect designing a house, and when he gets a picture of the proposed compound to suit him he goes into the laboratory to make it.

Perhaps what he makes may bear the hyphenated name "sodium-ditolyl-disazo-beta-naphthylamine-6-sulfonic-beta-naphthylamine-3.6 disulfonate"—the commercial contraction of which is "Brilliant Congo Dye"!

To sum up, the coal-tar yields ten primary products or "crudes," like benzene; these have yielded some three hundred "intermediates" like aniline; and from these have been created

literally thousands of dyes of all hues and shades. The history is very interesting, and it is briefly this. After some pioneer discoveries, a big step was taken by Hofmann, a student in Liebig's laboratory, who showed that brilliant colours could be obtained from certain coal-tar products chemically related to an aniline oil, which had been obtained long before by Zinin from natural indigo. Hofmann went to teach in the Royal College of Science in London, and he had as one of his students a boy of fifteen, William Henry Perkin. This genius was set to work to prepare artificial quinine, and in 1856 he discovered "mauve," the first of the aniline dyes, and a new substance in the world. Ten years later, he discovered how to produce artificially the colouring matter called "Turkey Red" or alizarin, which had previously been obtained from the root of the madder plant. At one time half a million tons of madder were raised annually in France, but after Perkin's discovery, as Professor Slosson puts it, "the madder fields of France were put to other uses, and even the French soldiers became dependent on made-in-Germany dyes for their red trousers. The British soldiers were placed in a similar situation as regards their red coats, when after 1878 the azo scarlets put the cochineal bug out of business." For it was from the body of the female cochineal insect (*Coccus cacti*), a native of Mexico to start with, that the scarlet colouring matter was obtained.

We must not linger over the story of the coal-tar colours—there are so many other creations to be discussed. What happened in regard to "Turkey Red" happened in regard to indigo, which came originally from an Indian plant, related to the British woad; in regard to Tyrian Purple, which came originally from a Mediterranean sea-snail (Murex); and so in many other cases. It is a matter for regret that when Hofmann returned to Germany he practically took the young industry with him—an instance of British lack of imagination and foresight. "By 1914 the Germans were manufacturing more than three-fourths of all the

coal-tar products of the world, and supplying material for most of the rest."

It must be understood that the coal-tar dyes are often good for much more than dyeing the robes of cardinals, the uniforms of soldiers, the Socialist's necktie, and even ladies' ribbons. Thus, to mention only one, the dye called "flavine" is a quick killer of the microbes of abscesses. And allied to the coal-tar dyes are many coal-tar drugs—many of them not unmixed blessings—like "aspirin," "phenacetin," "sulphonal," and "veronal."

Artificial Perfumes

Nothing derogatory is implied in the term "artificial," for why should indigo built up by the devices of the rational chemist be necessarily inferior to that elaborated in the indigo plant, or why should the musk made from a coal-tar product be necessarily inferior to that secreted by the musk-deer? That the artificially produced substance is not made in the same way as the naturally produced substance is certain, but chemically they are the same —when they are finished. It is possible that minute impurities or accessories cling about the natural product, which give it a charm of individuality like that distinguishing a woodcut from a zinc-block, or a wrought-iron gate from one of cast iron. In any case, the main fact in regard to perfumes, as in regard to more important products, is that man first sought laboriously for "the natural"; he then tried to adapt Nature to his purposes, e.g. by growing acres of scented flowers; and third, he has gone on another tack altogether—that of creating for himself. Thus the chief ingredient of attar or oil of roses is geraniol, which can be made synthetically, and the fragrance of orange flowers has been successfully captured by the artificial building-up of neroli.

What is true of perfumes holds also for flavours—appealing to the other chemical sense, taste, the twin-sister of smell. Thus vanillin, artificially synthesised in 1874, is extensively used, instead of the identical vanillin from vanilla-beans. Our only pro-

test is this: Let the natural and the artificial products compete fairly; let the æsthetes decide how far they are physiologically and psychologically equivalent; let us pay accordingly, if we please; but do not mix synthetic geraniol with attar of roses.

Synthetic Rubber

India-rubber or Caoutchouc is a gum that occurs in the milky juice of many plants, and abundantly in a few, especially in certain trees of the spurge and the fig orders. The milk flows out when the tree is cut; and rubber-trees are now cultivated in many places where they are not native. The material is used, as everyone knows, for tyres, waterproofs, goloshes, hot-water bottles, syringes, stoppers, and in hardened form as vulcanite. It has almost been forgotten that the name "rubber" referred to its early use as an eraser. Another gum known as gutta-percha is used for isolating submarine cables and making golf-balls.

When rubber is heated in a retort it splits up into a benzine-like liquid called "isoprene," and the synthetic chemist's problem was first to make this isoprene artificially and second to change it into caoutchouc. The whole story is an extraordinary one, but we can only say that isoprene can be made artificially in various ways, e.g. from the fusel-oil yielded by fermenting potato-starch; and that isoprene can be changed into caoutchouc in various ways, e.g. by drying it over metallic sodium. In 1912 there were exhibited in New York two automobile tyres of artificial rubber which had run a thousand miles. But while the problem has been solved scientificially, it has not been solved industrially. For it does not *pay* to get isoprene from potatoes or from turpentine. The most promising method is perhaps to heat coal and lime in an electric furnace. They unite to form calcium carbide, which in contact with water yields acetylene, and from this gas it is possible to make isoprene and therefore rubber. Yet it remains more profitable to go to the rubber-tree!

DISTILLATION OF ORANGE-BLOSSOM FOR PERFUMES

Photos: Jacques Boyer, Paris.

SORTING MILLIONS OF ROSES

TAPPING A RUBBER-TREE IN THE PUTUMAYO DISTRICT

The bark is first pierced to allow the liquid gum to run out into a small tin fixed below the incision. A giant spoon is dipped into the latex (or milk) and held over smoke, which is made by burning bits of the Urucury palm. Almost at once the milk congests and turns into the india-rubber of commerce.

Sugar-making

For many ages men knew of sweetness only from fruits and honey, but in the course of time they learned to press the sugar-cane. How this sweet reed was carried from the Far East to the West Indies is an interesting story, but it does not concern us here, nor how Napoleon was instrumental in rivalling the sugar-cane with the beet-root, which is rich in precisely the same sucrose (C_{12} H_{22} O_{11}). Of course all green plants make sugar, but only the cane and the beet—we need hardly count the maple—do so in sufficient abundance to be worth tapping, except through bees or as concerns their fruit. What the chemist has done in regard to sugar is to distinguish its different natural kinds; to make some new ones on his own, and to make it possible to get this valuable nutrient very pure. As Dr. Slosson says: "Common sugar is almost an ideal food. Cheap, clean, white, portable, imperishable, unadulterated, pleasant-tasting, germ-free, highly nutritious, completely soluble, altogether digestible, easily assimilable, requires no cooking and leaves no residue. Its only fault is its perfection. It is so pure that a man cannot live on it." In fact, to make it more than a fraction of the diet is dangerous; and some people with a slight twist in their chemical routine (metabolism) should not take it at all. And here is a point where the creative chemist came in. For an American investigator, Ira Remsen, afterwards President of Johns Hopkins University, accidentally discovered a coal-tar derivative, which he called saccharin, several hundred times sweeter than sugar, yet not a sugar at all. It has no nutrient value, but it flavours tea and coffee, and it is not injurious to those who cannot take sugar.

§ 2

Chemical Conjuring

We never tire of watching a conjurer who turns a crumpled handkerchief into a white rabbit, and that into a pigeon; but there is much more real conjuring in the chemical laboratory. The

chemist is a transformist. With a wave of his wand he changes soft unsaturated fats, which are apt to become rancid and smelly, into hard saturated fats which last and keep sweet. With another wave he transforms rank fish oil so that it can be used for soap or even for food. From beef-fat the chemist originally made margarine, but other sources of fat—from coco-nut and cotton-seed, from pea-nut and soya-bean—may now be added to this excellent "composite butter." The fact is the animal fats are being more and more displaced by vegetable fats. But our point was simply that with a little coaxing the chemist can change a material so that we do not know it when we see it, and that he can make excellent butter without applying to the cow.

Transformations of Cellulose

The cell-walls of plants are made of cellulose, a carbohydrate with the same formula as starch ($C_6H_{10}O_5$), which often hardens into wood. We necessarily eat cellulose when we eat cabbage and the like, but we do not get much good out of it, and it is more important in other connections. It has gone to make coal, it forms wood, and it is the convenient starting-point for many of the chemist's transformations. For although he may go back to the inorganic elements, carbon, hydrogen, oxygen, and nitrogen, it is much more convenient not to have to begin at the very beginning.

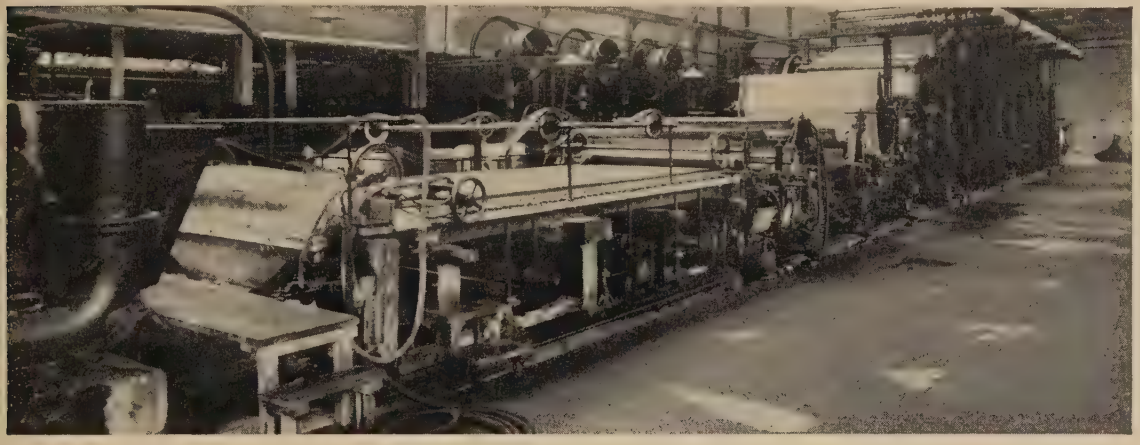
From wood-pulp most modern paper is made, and the delicate fibres seen in paper when examined under a microscope are the remains of the cell-walls of the plants. Cellulose is also used for paper cups and napkins, twine and suit-cases; but it is even more important when used along with other materials as in "mercerised" cotton, and the artificial silk this can be made to yield.

In this connection Dr. Slosson makes good use of the story of Nobel's cut finger.

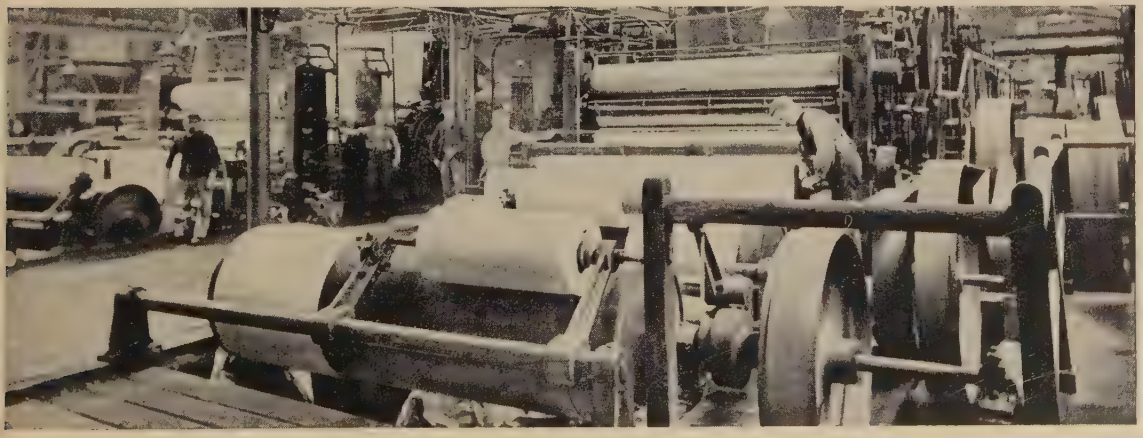
> Alfred Nobel was a Swedish chemist—and a pacifist. One day while working in the laboratory he cut his finger, as

PAPER FROM WOOD-PULP

Illustration of the beating machines, in which the wood-pulp (or similar fibrous material like esparto grass) is broken up, and, with the addition of water, reduced to a state like thin milk. This is then refined to remove foreign matter and lumps.



The liquid pulp is then pumped into a machine and passed over a wire-mesh, which moves continuously forwards and also from side to side. The liquid drains through and the fibrous materials are left, the complex movement disposing the fibres so that they interlace. A suction box over which the wire-mesh then passes removes any remaining water from the interwoven fibrous sheet, which has now become paper. To complete the process, the paper is carried on a blanket over a series of heated rollers, and thoroughly dried.



The "dry end" of the machine, showing the finished product—a continuous sheet of paper, which is wound into reels ready for use on the printing machine. A reel often contains more than five miles of paper.

Photo: West & Son, Southsea.

WHAT MODERN EXPLOSIVES CAN DO

A wooden beam has been blown up and completely disintegrated. Noteworthy also is the immense body of water raised by the force of the explosion.

> chemists are apt to do, and, again as chemists are apt to do, he dissolved some gun-cotton [cellulose treated with nitric acid in the presence of sulphuric] in ether-alcohol and swabbed it on the wound. At this point, however, his conduct diverges from the ordinary, for instead of standing idle impatiently waving his hand in the air to dry the film as most people, including chemists, are apt to do, he put his mind on it, and it occurred to him that this sticky stuff, slowly hardening to an elastic mass, might be just the thing he was hunting as an absorbent and solidifier of nitroglycerine [the liquid result of mixing glycerine with nitric and sulphuric acids]. So, instead of throwing away the extra collodion he had made, he mixed it with nitroglycerine, and found that it set to a jelly,

—the first of the high explosives of modern warfare. Everyone knows that this collodion is much used as "new skin," which has saved many lives, and in the cameras and cinemas that have made so many people happy. And one might go on to show how the cellulose of the saw-dust heap can be used to make the soles of boots, the cushions of the car, the celluloid of the toilet-table, and much more besides.

§ 3

Capturing Nitrogen

All living matter consists in part of proteins—nitrogenous carbon compounds, such as white-of-egg, casein, gluten. It follows that a normal diet—to keep this living matter agoing—must include a supply of nitrogen. Animals cannot utilise nitrogen except in the complex form of proteins which have been worked-up by other animals or by plants. Plants get their nitrogen supplies from nitrates, like saltpetre, and similar nitrogenous salts in the soil. Therefore it becomes of fundamental importance that the supply of nitrogenous salts in the soil should be kept up. To some extent this comes about very naturally when the withered residue of plants is, with the help of earthworms, incorporated

again in the soil, or when a dead animal is buried by sexton beetles and decomposes. The same result is reached when what remains of a crop is ploughed in or when the stable manure is spread upon the fields, and eventually takes the form of ammoniates or the like, which the plants can utilise.

On the other hand, when forests or coal-seams are burned by man fixed nitrogen is lost in the combustion, and the amount of free nitrogen in the atmosphere (four-fifths of the whole) is increased. Combined nitrogen is similarly lost when gunpowder explodes, and a small cannon shot, using up only a pound of gunpowder, destroys combined nitrogen to the extent of the free nitrogen in three million litres of atmospheric air. "In this sense," Professor Bunge writes, "it may be affirmed that every shot from a firearm kills, that it destroys life whether the ball strikes a living being or not. For no life is lost by the death of the individual; from the decay of the body equivalent new life arises. But the destruction of combined nitrogen means the definite diminution of the capital, upon the amount of which the total number of living beings depends." Obviously this is taking a very quantitative view of life. The vital equivalent of a lost leader is not calculable!

We see, then, that one of the farmer's main problems is to keep up the supply of combined or fixed nitrogen in the soil. A cheap way of doing this, referred to in the chapter on BOTANY, is to cultivate Leguminous crops with root-tubercles, for by means of the partner-Bacteria in the root swellings such plants are able, in a way not yet understood, to capture the free nitrogen of the air and fix it. If these crops are ploughed into the soil, in whole or in part, they will make it rich for other and more valuable growths. But this is a slow process, and what the farmer does is to manure his fields, with, in particular, a supply of nitrate brought from the saltpetre fields of Chile. But Chilian nitrates are expensive, and the supply is limited. Therefore we see the enormous importance of the chemist's discovery that nitrates can

Photo: James's Press Agency.

A NATURAL WELL OF PETROLEUM GUSHING UP FROM THE EARTH

In the photograph, one of the wells at Baku is shown on fire, throwing flames 200–300 feet high, surmounted by huge clouds of smoke. There is uncertainty in regard to the geological origin of petroleum. According to the theory that seems supported by the strongest argument it is the outcome of the natural distillation of great masses of buried vegetable matter.

Reproduced by permission of Price's Patent Candle Co., Ltd.

CANDLE MOULDING

One of the many products of Scotch shale is paraffin oil. Out of crude paraffin oil the candle factories freeze the solid paraffin that is largely used in making candles. Coloured candles are made from fats stained with aniline dyes.

The illustration shows candle moulding on a large scale. The melted material is poured into moulds. When the moulds are full the hot water with which they are surrounded is replaced by cold water, thus causing the candles to solidify.

Photo: L. E. A.

DAVY LAMP

Old. New.

The safety-lamp was invented by Sir Humphry Davy to prevent explosions from fire-damp in mines. The presence of explosive gas is indicated by the burning of the fire-damp in the interior of the gauze cylinder, the heat is conducted away, and prevents the flame from spreading to the gas in the mine.

be made at home. There are some Swiss valleys nowadays which are "glacier at one end and 98 per cent. nitric acid at the other." The chemist has discovered how to make fertilisers—and therefore bread—out of the thin air.

It has been known for a long time that a flash of lightning passing through the air may separate nitrogen atoms from one another and oxygen atoms from one another, with the results that some of the isolated nitrogen atoms unite with some of the oxygen atoms and yield nitric oxide—the first step to something better. What the chemist did was to substitute for the lightning a gigantic electric arc through which the air is run rapidly, lest the terrific temperature, e.g. 6,300° Fahrenheit, undo what it has done. When the energy for producing the electric arc can be obtained from a handy waterfall, whether natural or artificial, the relative cheapness of tapping the store of free nitrogen in the air is evident.

In Germany, where water-power is not so available as in Scandinavia, they hit upon another way of capturing the nitrogen of the air—the well-known Haber process. The elements used in this case are nitrogen and hydrogen, the result is ammonia (NH_3), and the agent is not an electric furnace but a quietly-working rare metal, such as uranium, osmium, or platinum, which acts in a mysterious way (as a "catalyst"), bringing elements that become intimate with it into union with one another. It is not to be supposed that the Haber process is a simple affair, for great pains have to be taken to get the nitrogen and the hydrogen in a very pure state before they are submitted to the catalytic action of the rare metal. Moreover, when the ammonia has been produced it has to be changed into the more useful form of nitric acid, which involves another appeal to a catalyst (a platinum gauze) in the Ostwald process. The extent to which the air is to-day "worked" for raw materials is very wonderful; such, for example, as oxygen, which is used extensively in engineering industries with acetylene to make intensely hot flame for welding

and other processes. Nitrogen, as we have seen, is obtained from the air on a great scale for the manufacture of fertilisers, the output of which is enormous. Argon and neon also are trapped from the air and are used in incandescent electric lamps.

We cannot leave the subject of "fertilisers" without saying a little about cyanamid. When a strong electric current is passed through a mixture of lime and coke, the metal calcium joins to part of the carbon, yielding calcium carbide (CaC_2), the stuff which along with water produces acetylene gas. Now if a stream of nitrogen be passed over hot calcium carbide it is captured and forms calcium cyanamid ($CaCN_2$), a stony material sold as a fertiliser ("lime nitrogen"). But if the calcium cyanamid be treated with superheated steam, it yields ammonia, and from ammonia can be produced nitric acid, and from that—fertilisers, which mean more bread.

It is useless to pretend, however, that this is more than one side of the story. For whether it be primitive gunpowder made by grinding up saltpetre, charcoal, and sulphur into a black powder, or nitroglycerine, or gun-cotton, or these two combined, or TNT, all the explosives of war depend upon the readiness of "the nitro group" (NO_2) to break up. For nitrogen does not readily combine with other elements, and when it does so it is very prone to break off the connection on even slight provocation.

The Potash Supply

A typical plant food is saltpetre or potassium nitrate. The nitrate part can now be snatched from the air instead of being dug from the guano-beds of Chile. But what of the potash part? "A ton of wheat," Dr. Slosson says, "takes away from the soil about 47 pounds of nitrogen, 18 pounds of phosphoric acid, and 12 pounds of potash." If the farmer is to go on, he must replace not only the nitrogen but the phosphorus and the potash. The world consumption of potash for agricultural purposes is enormous.

Now the great natural source of potash is at Stassfurt in Germany—a vast bed where the evaporation of sea-water floods left in bygone millennia crystalline deposits of the salts which had been dissolved out from ancient rocks, and left them well arranged! In 1913 the United States imported a million tons of Stassfurt salts for which the farmers paid over 20 million dollars. Obviously the potash supply has had to be looked for somewhere else, and the chemist has to lead the search. There are abundant salts of potassium in the rocks, e.g. the felspar of granite, but the difficulty is to get the potash out or to get it out cheaply enough. As Dr. Slosson says in his inimitable way, "A farmer with his potash locked up in silicates is like the merchant who has left the key of his safe at home in his other trousers. He may be solvent—but he cannot meet a sight draft. It is only solvent potash that passes current." Use is now made of the potash in wood ashes, the potash in the waste liquor of beet molasses, the potash in seaweeds, and so on, but the potash problem remains unsolved outside Germany.

Wealth out of Waste

In many cases, as we have seen, the chemist made a new thing, such as chloroform; in many cases he made an old natural product in a new artificial way, as in the case of indigo; but in other cases his ingenuity has taken the form of discovering a use for what was previously regarded as worthless. Let us take a few examples. For many a year no one thought of utilising the cotton-seed that used to be thrown away or burned when the precious fibre was collected. Nowadays it is used in half a hundred ways—yielding cotton-meal for cattle and oil for table use, writing-paper and putty, fertilisers and soap, varnishes and smokeless powder! Even from such an apparently trivial source as the seeds of the tomato-fruit, formerly discarded in the canning factory, there can be extracted over 20 per cent. of an edible oil. The chemist has led the world to a new economy.

Summary

The story of the chemist's achievements as a creator is one of the most brilliant chapters in the history of science, and not without its romance. We strongly recommend Dr. Edwin Slosson's *Creative Chemistry* (1921), a book that reads like a novel, to which we have been greatly indebted in writing this short article. We have not been able to give more than samples of what has been accomplished. What was procurable in small quantities and at great expense as a natural product can now be made artificially and cheaply. What was once procurable, but has become unavailable by reason of exhaustion or political changes, can be made from simple materials, and independently of any particular locality. Hundreds of entirely new things, which the world never saw before, have been synthesised. Vast quantities of material previously unused or thrown away as waste have been utilised as the foundation of new wealth. So the story runs, and there is no telling what chapters are to follow. It is by no means fantastic to suggest that some new biochemical discovery may alter the whole bread-and-butter problem of mankind. For a long time the chemical investigator was concerned with analysis; but to this he has added synthesis; and in so doing he has already made the world new—both for evil and for good.

BIBLIOGRAPHY

Findlay, A., *Chemistry in the Service of Man.*
Hendrick, Ellwood, *Everyman's Chemistry.*
Philip, James C., *Achievements of Chemical Science.*
Sadtler, S. S., *Chemistry of Familiar Things* (New York).
Slosson, Edwin E., *Creative Chemistry.*
Soddy, Frederick, *Matter and Energy* (Home University Library).
Tilden, Sir W. A., *Chemical Discovery and Invention in the Twentieth Century.*

XXIII

METEOROLOGY

THE SCIENCE OF THE WEATHER

THE aim of modern meteorology is to investigate the great ocean of air that surrounds our planet and to discover the laws that govern its circulation. A complete knowledge of these laws would render possible the forecasting of the weather for considerable periods, and thereby meteorology would prove itself to be a science of the greatest value.

Climatic conditions, more than anything else, limit the habitable area of the earth. Although there is probably no climate to which man cannot adapt himself, the coldest lands are either uninhabited, or sparsely populated like Northern Siberia for example. The influence of climatic conditions on race temperament is very pronounced, and has often far-reaching consequences. In the past history of the earth there have been great changes in the climate brought about by a succession of ice-ages; periods when vast areas of Europe and North America lay hidden beneath great fields of ice, when the great mountain-systems formed the cores of mighty glaciers, from which, after the ice-ages had been succeeded by warmer periods, great rivers flowed down and fed lakes and inland seas, where now there is nought but the sand of the desert, or at most some shrunken lakes with no outlet to the sea. All this occurred, however, ages ago, and though at the present time the earth's surface shows conspicuous belts of desert, there is no definite evidence of a general drying-up having occurred within historic times; in fact, in some places there is not wanting proof to the contrary. Thus, in Central Asia

desiccation does seem to be increasing, yet in the Sahara vegetation is said to be encroaching again upon the desert.

§ 1

The Causes of Weather

Weather changes are the result of the general turbulence of the atmosphere; the greater the turbulence the more profound will be the changes. The turbulence is due in the first place to the influence of the heat received from the sun, and it is increased by the effects produced by the earth's rotation and revolution; by the irregular distribution of land and water on the earth; by the variation, according to latitude, of the intensity of the incident solar heat; and also by the fact that the atmosphere, being a gas, is subject to changes of pressure and volume as well as of temperature.

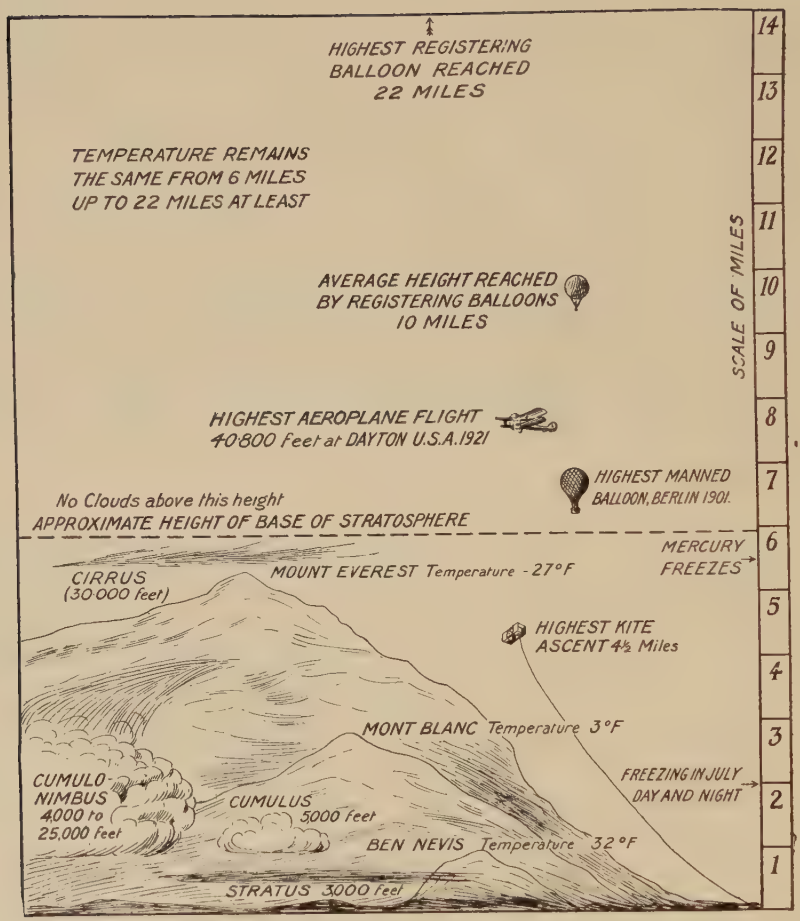
Although the mathematical and theoretical side of meteorology is now receiving close attention, it has been the observational side of the subject that has up to the present undergone the greatest development, and indeed it is most essential that the observation should form the basis of the theory, and that theory should conform to the facts. Therefore we find that in nearly every civilised country in the world there exists a meteorological organisation, generally a government institution, whose duty it is to obtain observational records and to employ them for the preparation of forecasts and for statistical purposes. In Britain the former Meteorological Office is now a special department of the Air Ministry.

The Two Regions of Atmosphere

Our planet is surrounded by a great ocean of air. The air itself is a mixture of gases, the chief of which, in the lower layers, are nitrogen and oxygen; much smaller quantities of carbonic acid gas and water-vapour are also present, together with the rare gas argon. In the upper layers the composition may be

THE CUMULO-NIMBUS, A DENSE RAIN-CLOUD OF CUMULUS FORM (See § 9, p. 783, Clouds.)

THE COMMON CUMULUS CLOUD. DARK AND OPAQUE IT SHOWS ITS SILVER LINING (See § 9, p. 783, Clouds.)



THE ATMOSPHERE AND HOW IT HAS BEEN EXPLORED

The diagram shows the heights of some well-known mountains, and the average heights of certain cloud-types. It also shows what heights have been attained by various methods of ascent. The dotted line shows the average height of the dividing line between stratosphere and troposphere in our latitudes.

different: hydrogen and helium are both believed to be present; the latest theory is that helium predominates.

So far, however, as temperature is concerned, the atmosphere is divided into two parts, a lower region in which there is a fairly rapid decrease of temperature with height, and an upper region where, as far as the limit investigated up to the present, such a condition does not prevail.

The higher layer, in which there is no material change of temperature with height, we call the "stratosphere." The lower layer, in which there is considerable lapse of temperature with height, we call the "troposphere." The region where troposphere changes to stratosphere is generally, but not always, marked by a sudden cessation of fall of temperature; sometimes the change is more gradual, but in almost all cases it is possible to define the level where the stratosphere commences. This level varies with the seasons and with the geographical position of a place; in our latitudes it is on the average about seven miles above sea-level. The temperature of either the stratosphere or the troposphere is of course not constant, but shows considerable variations. The point is, *that in the former case temperature does not decrease with height; in the latter case it does.* The belief once held that the higher we ascended the colder it would continue to become is therefore not true. Let us see how this astounding fact was revealed.

§ 2

Sounding the Upper Air

Of late a great deal of study has been given to the conditions that exist in the air above the earth, and, whenever possible, the chief stations investigate the upper air by means of balloons. Two types are used, one of which is a fairly large balloon called a registering balloon or "ballon sonde"; this balloon is sent up with a small instrument called a "meteorograph" attached to it. The balloon, set free, rises upward until it bursts,

when the meteorograph falls down to earth. The instrument is protected from injury by being enclosed in a light bamboo framework, while the remnants of the balloon fabric act as a parachute, so that the records obtained are usually recovered in good condition. A notice is attached to the instrument entitling the finder to a reward on handing the instrument in at any Post Office. The records made include pressure, temperature, and humidity, and the whole is contained on a small rectangular plate of silver-plated metal not much bigger than a postage stamp. A microscope is required to enable the traces to be read with accuracy, but the results are very dependable.

The other type of balloon is much smaller, usually only 18 to 24 inches in diameter when inflated, and is made of thin rubber, generally dyed some dark colour to render it easily visible. The balloons are termed "pilot balloons," and are sent up in considerable numbers every day at stations all over the country. They are inflated with hydrogen, and after being released they are observed in their flight by theodolites at either one or two stations. If two theodolites are used, the stations chosen are separated by half-a-mile or more, and the length of the base-line so formed affords a datum from which the balloon's position can be accurately determined. Both observers at the two stations take simultaneous readings every minute of the angular altitude of the balloon and of its azimuth (i.e. its horizontal angular position from the base-line), and from these readings the position of the balloon at each minute is obtained. A far more rapid method, however, is to use only one theodolite for taking the necessary position readings, and to assume that the balloon rises at a steady rate, which has been determined experimentally and found to be between 450 and 500 feet per minute for balloons of the size above mentioned. Knowing the height and the azimuth and elevation angles, the balloon's position can be rapidly determined by the use of a slide-rule. As a matter of fact, this second method is the one commonly employed at

meteorological stations, on account of its expedition, for it is quite possible to have all the results worked out by the time the flight has ended.

Observing the Tracks of the Balloons

The balloons follow curious tracks at times, especially at stations on our eastern coasts, when a sea-breeze may be blowing shorewards, for the balloon in such a case will travel westwards over the land, but as it is rising at the same time it will soon pass beyond the influence of the easterly breeze, and, if the wind above is from some westerly point, as is usually the case, the balloon will often return overhead across the station and be lost to sight far over the sea. At other times the track will form a wide sweeping arc, generally tending towards the right; occasionally the track will be a somewhat irregular spiral; in fact, it is the exception for the track to be a straight one. This means, of course, that the wind directions at various levels in the upper air are often very different from those at the surface, and this fact is of the utmost importance to aerial transport, for an aircraft can at times reach its destination more quickly by choosing a suitable level.

Astonishing Facts Revealed

Small as they are, these pilot balloons are often kept in view to very great heights; it is quite common for 20,000 feet (nearly 4 miles) to be reached, and half as much again has been exceeded, ere they have been lost to sight in the theodolite telescope. The larger registering balloons have reached even greater heights, for records have been obtained of the temperature and pressure up to fourteen miles above the earth's surface! And these records have a very curious story to tell us. In days gone by it was always believed that the higher we ascended the colder it would become until the cold of outer space was finally reached. But this is not so; the temperature does fall off with height until a certain level is reached, but above this level the temperature

remains practically unaltered as far as registering balloons have yet penetrated. In our latitudes this level is about seven miles up; over the Equator it is about ten miles, while in Polar regions it is lower, being there only about five miles. Now this fact introduces a rather curious paradox; because, if the air-temperature keeps on decreasing until the level is reached where temperature ceases to fall, it means that over the Equator the temperature at a height above ten miles must be lower than the temperature at a corresponding level over the Polar regions. And this is actually the state of matters, for, notwithstanding that the surface air at the Equator is much warmer than that in the Polar regions, yet the temperature at the ten-mile level over the Equator is about 110 degrees below zero Fahrenheit, while over the Arctic Circle it is only about 60 degrees below zero.

The existence of this level where the fall of temperature ceases means that we have to consider the regions above and below it as essentially different, and so, as we have seen, the two regions are named the "stratosphere" and "troposphere" respectively. Within the troposphere, where the temperature decreases with height, it is possible for heated air to rise upwards, because warm air is lighter than cold; but within the stratosphere this cannot take place, for when a mass of air rises the decrease of pressure causes it to expand, and the expansion lowers its temperature, so that it would become colder than the surrounding air; in other words, it would be prevented from rising.

The cause of the existence of the stratosphere has not yet been fully explained, but its effects are considerable. All turbulence of the air must occur below the stratosphere, and practically all the clouds must be formed beneath it. All our storms and changes of weather must therefore take place within the limits of the troposphere.

The Narrow Limits within which Life is Possible

When we take into consideration the rate of fall of temperature with height, the effect of which is forcibly demonstrated

A PILOT BALLOON READY TO BE RELEASED

Behind the observer is the specially constructed theodolite by which the track of the balloon is observed and its direction and velocity measured at suitable intervals. Valuable information is obtained by means of these balloons. It is quite common for them to reach a height of four miles; sometimes they reach a height of six miles before they are lost to sight. Larger registering balloons have even reached fourteen miles. It was by means of these latter that it was discovered that the air temperature does not go on decreasing after a certain height.

STRATO-CUMULUS CLOUDS IN A SUNSET SKY

The hazy white cloud is Cirrus—much higher than the dark Strato-cumulus. (See § 9, p. 783, Clouds.)

A DAPPLED SKY WITH A FLOTILLA OF FINE SMALL CUMULUS CLOUDS (See § 9, p. 783, Clouds.)

by the snow-capped mountains even in Equatorial regions, it will give us food for reflection to remember that all the teeming life on our planet is rendered possible by a thin zone of air approximately three miles deep at the Equator, and thinning out northward and southward till it ends at the ground-level in the neighbourhood of the Arctic and Antarctic Circles. Of the whole extent of our atmosphere this belt or zone is all that has a temperature above freezing-point.

§ 3

Pressure and Temperature

Atmospheric disturbances, then, have their origin in changes of temperature and pressure. Temperature is a fundamental element in Meteorology. The surface of the earth derives its warmth almost entirely from the sun. The rays of light and heat which emanate from the sun fall upon the surface of the earth, causing an increase in its temperature. As there are great differences in the nature of the earth's surface, there are consequently great differences in the warming effect produced. Land, for instance, heats up very rapidly, while water becomes warmed much more slowly. The air is not heated by the passage through it of the sun's rays, but by contact with the surface of the earth. The land and water surfaces communicate their heat to the air lying above them, and so in summer, and at midday, the air over the land will be much warmer than that over the neighbouring ocean. But, on the other hand, the water does not part with its heat so readily as does the land, and therefore in winter, and at night, the air over the land is generally colder than that over the ocean.

The atmosphere is, as we have already stated, a mixture of gases, and all gases possess certain properties in common. When heated, gases expand in volume, and when cooled, they contract. If a gas is expanded, or, in other words, if its volume is increased, it becomes cooler, and if compressed its temperature increases.

And if the pressure of one portion of a gas increases, there will be a flow of gas towards the other portion which is at lower pressure, and in the case of our atmosphere this transference of air is made very evident to us as wind.

Now if the air over one part of the earth's surface becomes heated to a higher degree than that over surrounding parts, the heated air will expand, and, in doing so, it causes the air layers above it to become compressed. These layers will then have a greater pressure than the surrounding air at the same levels. A flow of air, therefore, takes place towards the region where pressure is lower, and this additional air will, in turn, compress the air in the layers below it, so that now there will be greater pressure in the surface air surrounding the heated area, and the air at the surface will commence to move towards the heated area from all sides, and a "circulation" will thus be established, with the result that a wind will blow.

A rough illustration of a circulation is found in what happens when a window in a heated room is opened top and bottom; the warm air will flow out at the top, and cooler air will flow in at the bottom to replace it.

Small local atmospheric circulations are found everywhere, and every day, all over the world; but, because the sun's heating power is so very much greater in Equatorial regions than elsewhere, and because in higher latitudes the sun's altitude in the heavens varies considerably during the course of a year, it follows that great seasonal changes of temperature must occur, and also that great seasonal circulations are set up in the atmosphere like great currents in the ocean, and *these great seasonal circulations dominate the weather and its changes.*

§ 4

The Effects of Turbulence in the Atmosphere

The turbulence that takes place within the lower layer, or troposphere, is much too complicated to describe in detail, but its

broad features are indicated in the general circulation of the wind and the distribution of pressure and temperature on the earth's surface. Along the Equator there exists a belt of calms, called the "doldrums"; this belt is the mainspring of the great atmospheric currents, for here the maximum effect of the sun's heat is felt; the heated air is rising and overflowing in the upper regions. To take the place of this rising air, a further supply flows in from north and from south, and this supply comes from the neighbourhood of the Tropics of Cancer and Capricorn respectively.

Now these winds are moving over a globe rotating on its axis, and a curious thing happens to the winds on account of this rotation of the earth. Every passenger who has boarded a tramcar as it is turning a street corner has experienced the sensation of not being able to walk straight along the car, but being thrown to the side instead. The reason is that the passenger tends to keep moving in the direction of which he began, but the car is twisting beneath him. So it is with the wind which moves over the earth's surface above or below the Equator—the earth's surface is twisting beneath the wind, and thus the wind appears to become deflected from its original direction relative to the surface of the earth. The air which surrounds us is, in a word, being carried along with the revolving earth, just as the passenger is being carried by the car, but as the wind can move independently of the earth (or the passenger independently of the car), a change in the direction of the latter produces an *apparent* change in the direction of the former. In the Northern Hemisphere the deflection is to the right, and in the Southern Hemisphere to the left.

The Trade Winds

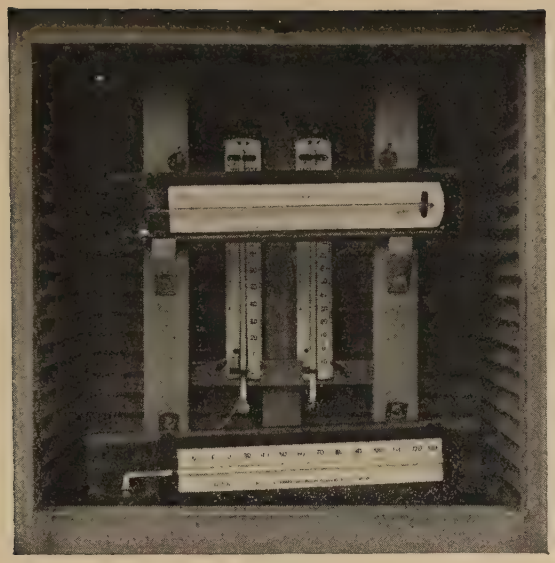
Therefore the winds moving southward and northward towards the Equator become deflected, and are found blowing from north-easterly and south-easterly directions respectively. These

winds are called the N.E. and S.E. "trades," and are remarkably constant winds. Now the air that has risen at the Equator moves out towards north or south *above* the trade winds, and for the reason above mentioned its direction becomes S.W. or N.W. These upper winds are known as the "anti-trades," and they descend slowly in the regions of the Tropics, where there exist other belts of comparative calm called the "horse-latitudes." To the north of the Tropic of Cancer there is a main drift of surface wind from the S.W., while in the Southern Hemisphere there is a similar surface current from about W.N.W. in the corresponding region. In the upper air these directions become more nearly westerly. In the Southern Hemisphere these winds are so well established as to be known as the "roaring forties," but in the Northern Hemisphere they are not so definite in direction. This is due to the predominance of sea in the Southern Hemisphere, whereas in the Northern one the land and sea areas are more equally divided. As already mentioned, land and water surfaces behave very differently under the influence of the sun's heat: land becomes rapidly heated, and cools with great rapidity; water is slow both to get heated and to lose its acquired heat. In summer we find areas of high pressure and low temperature over the oceans just north of the Tropic of Cancer and south of the Tropic of Capricorn, while areas of low pressure and high temperature exist over the great continents. When winter comes the high pressure with intense cold is found on the continents, while the sea is now the region of warmth and low pressure. These seasonal variations are much more strongly marked in the Northern Hemisphere than in the Southern one.

§ 5

The Indian "Monsoon"

One very important effect of the seasonal change is to be seen in the "monsoon" which occurs with wonderful regularity



THE STEVENSON SCREEN FOR RECORDING TEMPERATURE

The instruments are housed in a box of special design; four thermometers are mounted inside; the two in a vertical position are known as the Dry and Wet bulbs; the former registers the actual air temperature, the other gives a somewhat lower reading (see text). The thermometers arranged horizontally show the highest and lowest temperature occurring during any given period.

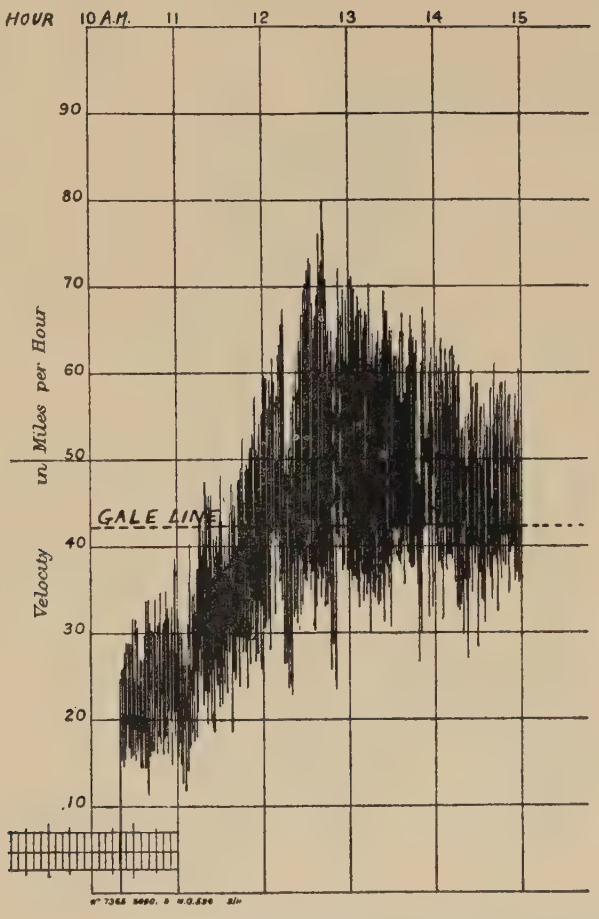
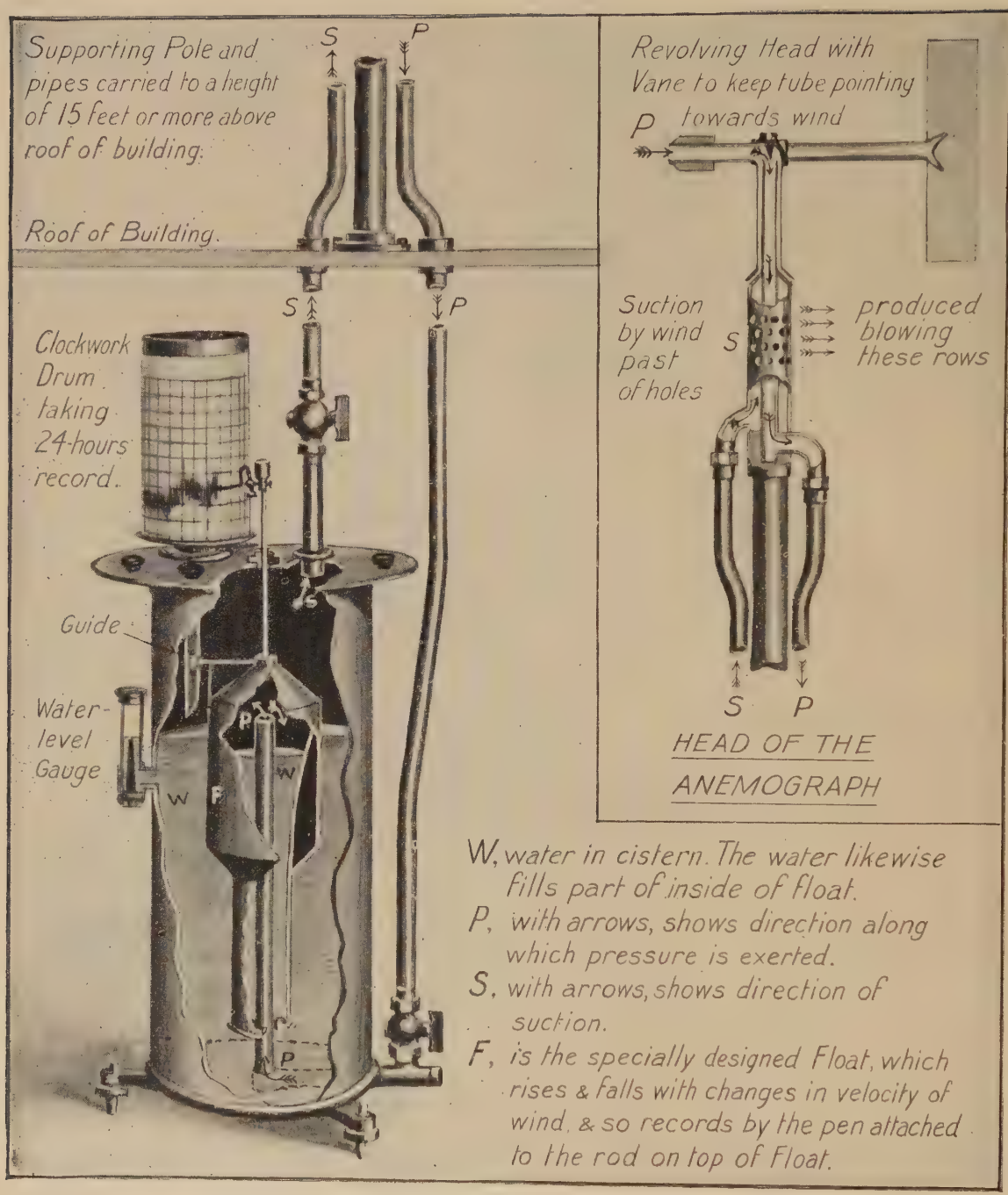


ILLUSTRATION OF A RECORD OBTAINED BY THE PRESSURE-TUBE ANEMOGRAPH DURING A GALE

The velocity in miles per hour is shown at the side, and the point where gale velocity (42 miles per hour) commences is shown by the dotted line.


Supporting Pole and pipes carried to a height of 15 feet or more above roof of building.
Roof of Building.
S
P
Clockwork Drum taking 24-hours record.
Guide
Water-level Gauge
W
F
Revolving Head with Vane to keep tube pointing towards wind
Suction by wind past of holes
produced blowing these rows
HEAD OF THE ANEMOGRAPH
W, water in cistern. The water likewise fills part of inside of float.
P, with arrows, shows direction along which pressure is exerted.
S, with arrows, shows direction of suction.
F, is the specially designed Float, which rises & falls with changes in velocity of wind, & so records by the pen attached to the rod on top of Float.

HOW WIND-VELOCITY IS MEASURED. THE DINES PRESSURE-TUBE ANEMOGRAPH

The change of pressure produced by the altering velocity of the wind is transmitted through the pipes from the head of the instrument; and the pressure thus exerted upon the surface of the water inside the float causes the float to rise and so brings the recording pen into action. The suction helps the instrument to act more effectively.

every year over India. During the winter, the winds blow over this country from the north-east; these winds are blowing outwards from the region of high pressure that then covers all the north-east of Asia; the winds are therefore cool and dry. But with the arrival of summer the Asiatic high-pressure gives way to a general low-pressure distribution, the centre of which lies over Persia and Baluchistan. At the same time a region of high-pressure is found in the southern Indian Ocean between Madagascar and Australia, and the air which moves from this "high" area towards the "low" centre will in the Northern Hemisphere be deflected to the right, as already explained, and so will have a south-westerly direction instead of a southerly one as it approaches the Indian coast. This air has been travelling over a wide expanse of Equatorial ocean, and therefore contains a vast amount of moisture in the form of water-vapour. When the wind arrives at the west coast of India it encounters there the long ridge of mountains that runs all down the Malabar Coast, and the mountains become a barrier which the wind has to surmount before it can continue its course. The air is therefore forced upwards, its pressure is decreased; thereupon it becomes cooled and can no longer retain the water-vapour that was easily held by the warmer air. The capacity of warm air for water-vapour is very much greater than that of cooler air, and, if air is cooled, any surplus of water-vapour is forced to condense out as cloud, and eventually as rain. Thus it is that the S.W. monsoon wind brings torrential rain to the west coast of India. Similarly the air streaming up the Bay of Bengal meets with mountain barriers in southern Assam and along the Burmese coast, and here again the rainfall is terrific. The moisture still remaining in the air is brought down finally on the southern face of the Himalayas, when the air encounters that mighty mountain-wall, and this region also has heavy rain. It is believed that Cherrapunji in southern Assam has the heaviest rainfall in the world, nearly 500 inches falling in a year.

§ 6

RECORDING METHODS

The Organisation of a Meteorological Service

In countries possessing an official meteorological service the general plan adopted is that of a central office where the forecasts are prepared and issued and the statistics dealt with, and with this central office there is associated a large number of "observatories," "telegraphic recording stations," and "climatological stations," all of which deal in greater or less detail with the recording of the meteorological elements. The observatories and telegraphic reporting stations take simultaneous observations at certain definite hours, and transmit these observations immediately in code by telegraph to the central office, where all the observations so made are plotted upon a map of the country, and from the map so drawn certain inferences as to the probable course of the weather are made by the staff whose duty it is to prepare the forecasts. In this country the hours for sending these telegraphic reports are 7 a.m., 1 p.m., and 6 p.m., and at some stations also at 1 a.m.—all times being Greenwich mean times.

The observations usually sent are those of pressure, temperature, wind direction and force, humidity, visibility, sunshine, rainfall, cloudiness, general character of the weather, and certain other more technical details. In order to obtain these data the more important stations are equipped with a considerable instrumental installation, while at the smaller stations some of the observations, such as those of wind force and direction, are made by personal estimation, in which a very high degree of accuracy can be attained by an intelligent and painstaking observer.

Recording Instruments

The instrument used for recording pressure is a barometer, which in its standard form consists of a glass tube about 36 inches long and ¼ inch or ½ inch in diameter; the upper end of the

THE RAINBOW

The beautiful colours of the rainbow are produced by the reflection and refraction of the sun's rays by the raindrops. Consequently rainbows are seen on the opposite side of the observer from the sun. When the sun is near the horizon the rainbow forms an arc which is nearly a semi-circle. If the sun is higher in the heavens the rainbow forms a smaller arc and appears lower in the sky, but the radius of the arc is always the same. In the ordinary rainbow the red is outside and the violet inside; if there is a double rainbow, the colours in the outer one are reversed. It is to be noted that the sky is much darker outside the bow than within it. The colours of the rainbow are not always exactly the same; slight variations in the tints and widths of the colours being occasionally found. These variations are due to differences in the sizes of the raindrops that produce the bow.

tube is closed, while the lower end is open and dips into a cistern containing mercury. The tube is first of all filled completely with mercury and the open end is carefully covered—as, for example, by the finger—so that no mercury can escape from, nor air enter, the tube; then the tube is inverted and the open end immersed in the cistern of mercury. If the finger is now removed the mercury in the tube will be seen to fall until the top of the column stands somewhere about 30 inches above the level of the mercury in the cistern, and the space that is left between the top of the mercury column and the upper end of the tube is an absolute vacuum. The column of mercury in the tube is prevented from running out completely by the pressure exerted by the atmosphere on the surface of the mercury in the cistern, and this implies that the weight of the mercury column must be exactly balanced by the weight of a column of air of equal cross-section, but extending from the surface of the mercury in the cistern up to the absolute limit of the earth's atmosphere. Therefore, when we talk of the rising and falling of the barometer it means that the length—and, therefore, weight—of the mercury column is increasing or decreasing, and that the weight—or pressure—of the counterbalancing air column is changing sympathetically. In other words, in the barometer the pressure due to the weight of mercury is equal to that exerted by the atmosphere.

Photography Used for Recording Purposes

In the chief observatories a simple barometer is mounted in an ingenious form of camera, and a continuous photographic record of its fluctuations is obtained upon a sheet of bromide paper mounted on a cylinder, which is rotated by clockwork. The record thus obtained is called a "barogram," and is amenable to the most accurate measurement, its tabulated readings forming a basis for statistical analysis of pressure variations.

Another instrument used for recording pressure is the

aneroid, which consists essentially of a small thin circular corrugated metal box from the interior of which the air has been exhausted, thereby forming a vacuum within the box. The air-pressure acts upon the sides of the box, causing them to yield or to recover against the action of a spring, and by a system of levers these movements are communicated to a hand which moves over a dial upon which a scale is engraved. The aneroid is a convenient and portable instrument, but is much less sensitive and accurate than the mercury barometer. Its chief application in meteorology is in the form of the familiar "barograph," an instrument wherein eight of these small vacuum boxes are superposed, and their combined movement is magnified by a system of levers and transmitted to a pen, which then traces a record of the movement upon a paper chart mounted upon a drum actuated by clockwork and making usually one revolution in a week. The trace thus obtained is a very useful and reliable guide to the pressure changes in progress.

The temperature of the air is recorded by means of thermometers, instruments whose appearance is very familiar to everyone. A thermometer consists of a glass tube having an extremely narrow bore, which is enlarged at one end into a bulb, either spherical or cylindrical in shape. The bulb is filled with mercury, which likewise fills part of the narrow bore in the stem of the thermometer. If the temperature increases the mercury in the bulb expands and the column in the bore rises, while a cooling of the air causes contraction of the mercury and a decrease in the height of the column.

The Stevenson Screen

Meteorological stations are equipped with a set of thermometers for recording various facts regarding the temperature. The instruments are housed in a box of special design known as a "Stevenson Screen." This is usually about 20 inches wide from east to west, 13 inches deep in the north-south direction, and 14

inches high from floor to roof inside measurements. The roof is double with an air-space between, and the sides of the box consist of a double set of louvres, while the bottom also is so constructed as to provide free ventilation to the thermometers within, though at the same time preventing sunshine from falling upon them. The screen is placed over grass at a height of 4 feet, and the site is so chosen that it shall be as open as possible to ensure the true atmospheric temperature being recorded. The screen and stand are always painted white both inside and outside as a further precaution against the effects of the sun's heat.

Inside the box there are usually mounted four thermometers, two of the ordinary pattern in a vertical position on a frame; one of these has its bulb covered with thin muslin, which is maintained always in a damp condition by water which is drawn by capillary attraction along some threads of cotton wick from a water vessel kept beside the thermometer. These two thermometers are known as the Dry and Wet bulbs respectively. The dry bulb registers the actual air-temperature, while the wet bulb gives a reading somewhat lower. This is due to the loss of heat caused by evaporation taking place from the wet muslin, and the difference in temperature between the bulbs is greater in dry weather than in damp, because evaporation is much more rapid when the air is dry. Consequently, from a comparison between the readings of the two thermometers we can obtain the degree of moisture of the air, or the "relative humidity" as it is termed. In foggy weather there is little or no difference between the two readings, but in showery weather there is often a considerable difference, so that, even though rain may be falling, it does not necessarily follow that the air is damp.

On other frames, but arranged horizontally, are two other thermometers of somewhat different pattern; these are used to determine the highest and lowest temperatures that have occurred during any particular period, and are known as maximum and minimum thermometers.

§ 7

Wind Recording

For obtaining records of wind force and direction the standard instrument now employed is the Pressure Tube Anemograph, invented by Mr. W. H. Dines, F.R.S. There are some slight differences in detail in the more recent models, but all patterns work on the same general principle. A steel pole varying in height between 15 and 80 feet, according to circumstances, carries at its top a movable vane which is really an open tube, the mouth of which always faces the wind. By means of a system of connecting pipes the wind-pressure at the mouth of the vane is transmitted to the recording part of the instrument. This consists essentially of a hollow water-borne float to which a recording pen is attached. The change of wind-pressure causes the float to rise and fall, and so moves the pen over the chart. The pen pulses up and down with every fluctuation of the wind, and the record obtained shows a broad ribbon-like trace, the middle of which gives the average velocity of the wind, while every single gust is recorded. In gales the average wind velocity may be about 50 miles per hour, but the individual gusts may reach to over 80 miles, while the lulls may sink to about 20 miles. The highest gust yet recorded in the country was of one of 110 miles per hour at Quilty during the storm which swept northwards across Ireland on 27th January, 1920.

In addition to the velocity and gustiness of the wind, this anemometer records also the direction from which the wind is blowing. The movements of the vane are transmitted by an attached rod, which passes through the hollow pole-support directly down to the recording part, where the variations of direction are traced on the same chart just below those of the velocity.

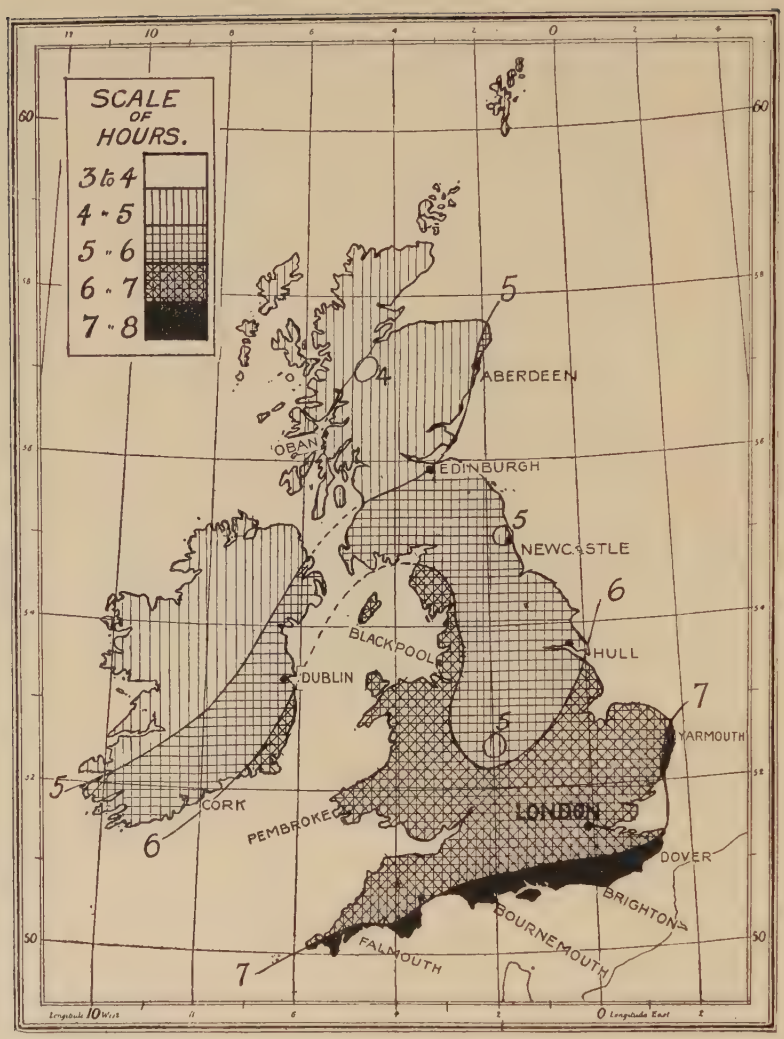
An older form of recorder, the Robinson Cup Anemometer, gives a record only of the mileage run by the wind in an hour. The

THE ROBINSON ANEMOMETER

The revolving hemispherical cups are being held still for the photograph to be taken. The wind-speed is measured by the rate of rotation of the cups. Below the cups are the vane-wheels which, acted upon by the wind, record the wind-direction by suitable gearing. The small instrument low down on the right is a Campbell-Stokes Sunshine-recorder.

PHOTOGRAPH COPY OF A SUNSHINE RECORD

The dark line shows the charring of the card by the heat of the sun's rays. When the sun is shining strongly the card is charred right through, as shown in the illustration. The vertical white lines are hour-lines, and it will be noticed from the horizontal white line that the sun was shining continuously from 10.30 a.m. till about noon, while between noon and 1 p.m. the sunshine was rather intermittent.



DAILY DURATION OF SUNSHINE IN JULY

The map shows how much sunshine on the average is received daily throughout our Islands in July. The dullest spot is in Inverness-shire, near the Caledonian Canal, and, in spite of the fact that the north of our Islands has a longer summer day than has our southern coast, the amount of sunshine increases steadily southward. Note how very much favoured are the south and east coast watering-places, and also how the sunshine is diminished in the area between the Black Country and the Tyne—partly at all events by the smoke palls over the great manufacturing centres. The cloudiness of the north-west coasts is due to the moisture-laden westerly winds from the ocean.

Robinson anemometer is also fitted for recording direction as well as velocity.

Rain Recording

The rain that has fallen during any period is registered by collecting the rain in a gauge, which is simply a funnel of circular cross-section with deep edges. From this funnel the rain runs into a collecting vessel, and is measured in a glass graduated to read in hundredths of an inch or in tenths of a millimetre. The gauges or funnels are usually of either 5 or 8 inches in diameter. A more detailed record is obtained by the Hyetograph, or self-recording rain-gauge, of which there are many patterns, most of them registering by the action of the weight of the water collected from the gauge-funnel into a floating vessel to which a pen is attached. When this vessel becomes filled with rain the pen is at the bottom of the chart, and an automatic syphon comes into action, emptying the vessel and preparing it for further recording.

Sunshine Recording

The instrument for registering the duration of sunshine is the Campbell-Stokes sunshine recorder. It consists of a metal frame forming half of the central zone of a sphere. Within the arms of this frame there is placed on a small pillar a sphere of glass which acts as a universal lens, whose focus falls exactly on to the inner surface of the frame. The frame is adjusted to the latitude of the station so that the focused image of the sun's path is parallel to the edges of the frame, and in the frame are cut three sets of grooves to hold specially prepared cards that will char without igniting. Owing to the changing altitude of the sun in the sky as the seasons advance, separate types of cards are used for winter, summer, and the equinoctial periods, and these cards are placed in their respective sets of grooves. Whenever the sun shines, its light and heat are focused exactly on to the surface of the card, with the result that a charred trace is left to record the fact.

§ 8

CYCLONIC DISTURBANCES

Cyclones and Anticyclones

Cyclones and anticyclones are names familiar to everyone who pays attention to weather reports. They are terms applied to those erratic changes which take place within the great general circulation of the atmosphere which has been already described.

Within the Tropics sudden sharp revolving storms, known locally as "hurricanes," "whirlwinds," and "typhoons," sometimes spring up and cause immense havoc. These storms usually cover a limited area, and follow well-defined tracks. The "tornado" of the United States often leaves behind it a track about ten miles long and only a few hundred yards wide, but within this track destruction is singularly complete.

In our latitudes, however, the cyclonic disturbances are much more frequent and are not nearly so severe; but they cover a much greater area, being sometimes 1,000 miles in diameter.

The cause of these disturbances has been stated to be due to the irregular heating of the land, and to the rapid ascent of warmed air in the case of the tropical storms. But for those disturbances in our latitudes, the meeting of two great air currents of different temperature has been regarded as the chief cause by some meteorologists; others believe they are due to changes that take place in the temperature of the stratosphere—the upper layer of the atmosphere.

Probably all these causes contribute in some measure towards the production of the differences in pressure that give rise to the violent winds.

The Formation of Cyclones and Anticyclones

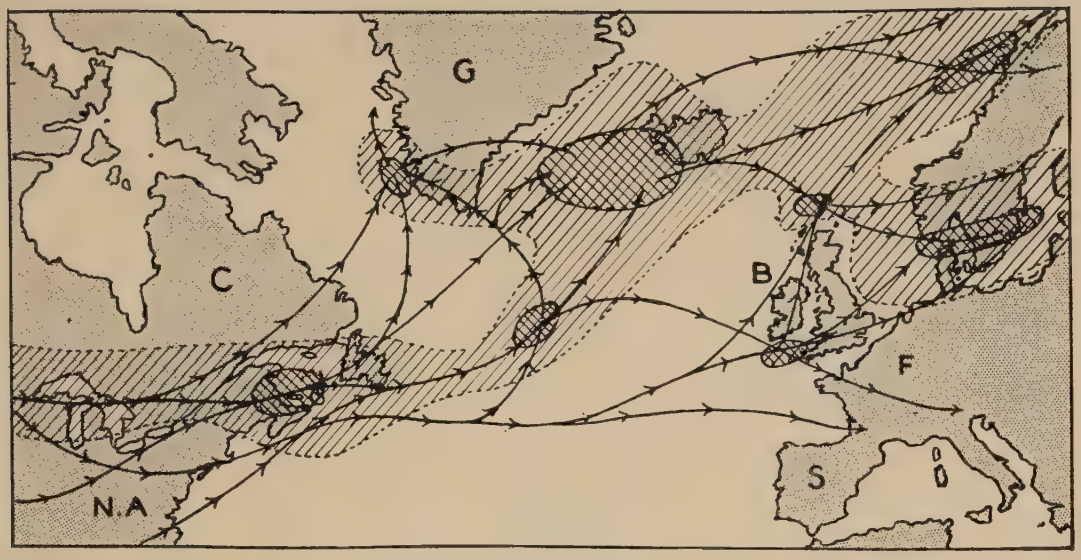
Now air, as we have seen, tends to flow from high-pressure areas towards low-pressure ones, just as brooks run down a hill to seek the valley, but this air will, in the Northern Hemisphere, be

deviated towards the right by the effect of the earth's rotation, as already explained, so that a system of large eddies will be set up in the atmosphere and there will be a tendency for the air to circulate round regions of high pressure in a direction similar to that of the hands of a clock, while round low-pressure areas the direction will be counter-clockwise. All our changes of weather are due to these circulating systems whose names are made familiar in the daily weather forecasts: the "low-pressure system," which used always to be termed a "cyclone," is now more commonly referred to as a "low," or a "depression." The high-pressure system is spoken of as an "anticyclone" or "high." The anticyclone may be regarded in general as the normal settled weather, while the depression bespeaks bad and usually stormy weather.

The cyclonic depressions form and develop chiefly along a belt which stretches from the great lakes of America across the Atlantic to north-western Europe, and they are much more numerous in winter than in summer. It is worthy of note that at this season there is extreme cold in central Canada, while the combined influences of the Gulf Stream Drift and the general south-westerly current of wind across the warm ocean maintain a temperature on the coast of Norway fully 25° F. warmer than that found in the Gulf of St. Lawrence, about 1,000 miles farther south. Then there is a cold ocean current streaming down past Labrador from Baffin's Bay, and a steady flow of cold air is sweeping from off the ice-clad plateau of Greenland. The temperature conditions are therefore very complicated and very favourable for the development of the depressions. The depressions formed over America move generally north-eastward towards Greenland, while those reaching our neighbourhood usually commence out on the Atlantic, and either skirt our Islands in a north-easterly direction towards northern Norway or move across them on an easterly course to the Baltic.

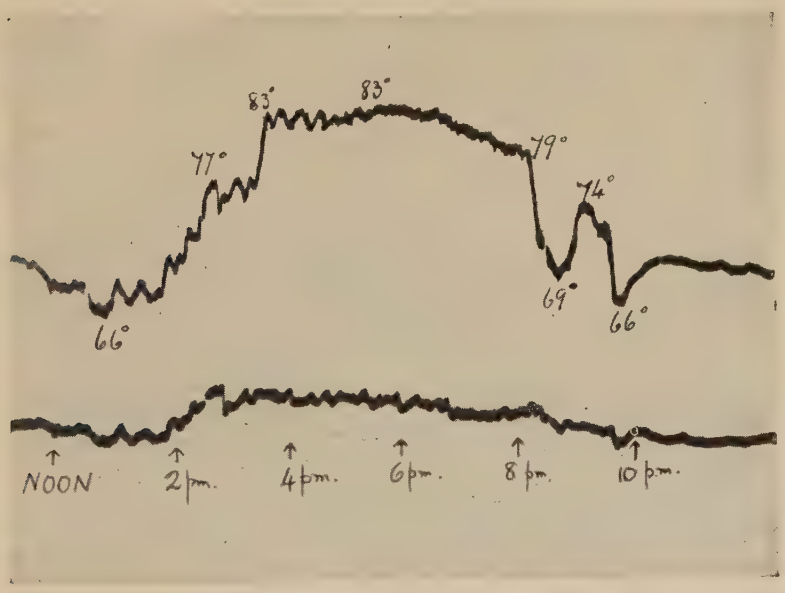
Let us see what happens when one of these depressions passes over our Islands. For the purpose we will assume that for some

days there has been a spell of fine quiet weather, with cloudless sky and a steady high barometer, all over the country. Then one morning the observers at the stations in the West of Ireland see a few slight traces of "mare's tail" cirrus cloud low down on the western horizon. Gradually these clouds, which are five miles high, move up from westward till they are overhead. Behind them the lines of cirrus become denser and eventually close up into a complete thin cloud-sheet, in which there may be seen a "halo" round the sun. Meanwhile a wind has begun to blow from the southward, and on examining their barometers the observers see that a fall has now commenced, which is slow at first, but which, as time goes on, becomes faster. The sky is now covered with a sheet of heavy leaden-grey cloud, in which a "watery" sun can be seen dimly shining. This cloud is called "alto-stratus," it is only one-half as high as the cirrus seen before it, and this means that water vapour is condensing out of the air in increasing quantity. Time passes, the barometer is now falling rapidly, while the southerly wind is blowing with increasing force, and still lower cloud of the "nimbus" type has formed and from it rain has begun to fall. The wind continues to blow harder till it reaches a gale, or even storm force, that is, from forty to seventy miles an hour, and rain falls more heavily. But presently the fall of the barometer begins to slacken, and then ceases, while the wind becomes lighter and rapidly changes from south to south-west, and then swings rather suddenly into the west or north-west. At this moment the barometer begins to rise, and either then or shortly afterwards the rain ceases, and in the west the sky commences to clear. The north-west wind is now blowing almost as strongly as did the southerly one, while the barometer is rising fast and the sky is clearing rapidly. Some squalls and showers may occur, but soon all is fine weather once more. It is, however, noticeable that the north-westerly wind is considerably cooler than the southerly one that preceded it. Why should this be the case? The theory suggested by the famous Norwegian meteor-



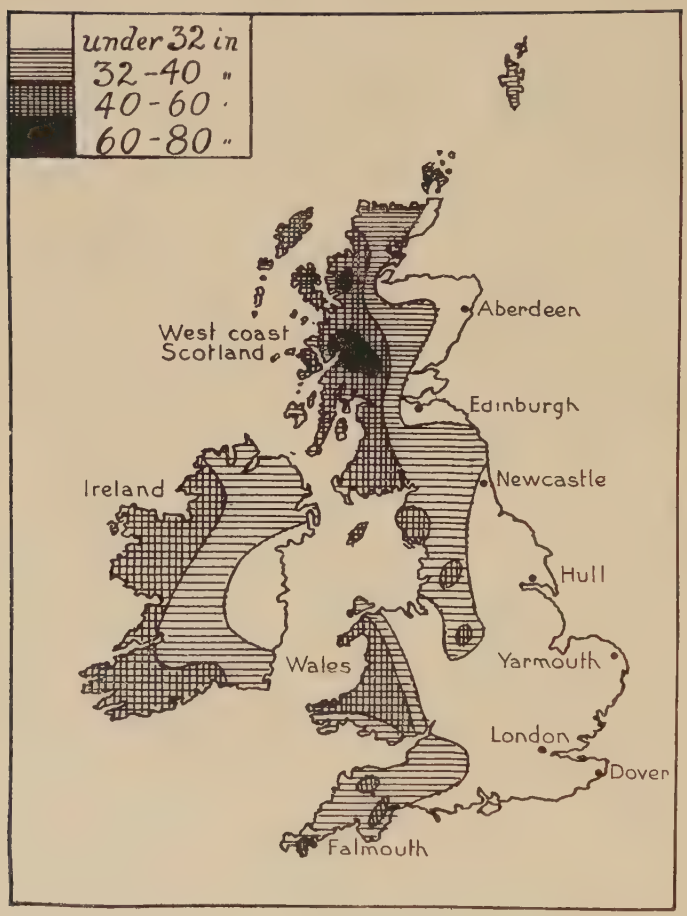
STORM-TRACK MAP OF THE NORTH ATLANTIC

The lightly shaded area shows the region of most frequent depressions; the darker areas are favourite points upon which the storms converge, and whence they disperse; while the barbed lines show the general routes they take.
B, The British Isles; F, France; S, Spain; G, Greenland; C, Canada; N.A., N. America.



THE RAPID VARIABILITY OF TEMPERATURE

Upper line, the "dry" bulb; lower line, the "wet" bulb. A copy of a record, obtained by the photo-thermograph, showing the arrival of a short "heat-wave" one summer's afternoon. On the upper line note the rapid rise of 17° F. between 1 p.m. and 4 p.m.; and the almost sudden drop of 10° just after 8 p.m. The lower line is a simultaneous record from the "wet" bulb, and shows the effect of evaporation on the temperature. The great departure of the upper trace from the lower one between 4 p.m. and 8 p.m. means that the hot air was also very dry, much drier than was the air before and after that time.



HOW THE ANNUAL RAINFALL IS DISTRIBUTED IN THE BRITISH ISLES

The prevailing moist south-westerly wind and the mountainous regions in our Islands combine to make our west coasts much wetter than our east coasts.

ologist, Bjerknes, is that in a cyclonic depression there are two main streams of air that converge upon each other. One of these is a southerly current, warm and moisture-laden from its passage over the Atlantic; the other is a cold dry polar current from the Arctic regions. They meet, and the warm air, being lighter than the cold, is forced to rise over the latter, and in doing so carries up with it the water-vapour it contains. The warm air, being thus forced up to a higher level, has its pressure decreased, and therefore becomes cooler (as has already been described), and its water-vapour is condensed into cloud, and finally falls as rain, because cold air cannot contain as much water-vapour as warm air can.

If the sequence of weather-changes occurs in the order just described, an observer may know that the centre of the depression has passed to the north of his station; but should the cyclone centre be to the south instead, the observer would experience a less marked difference in temperature, he might probably have more rain, and the wind would shift in the other direction, becoming first easterly, then gradually northerly, and, finally, north-westerly.

Our Wet West Coasts

The mountain chains in our Islands form a barrier to the wind and cause a forced rising of the air, which is attended likewise by the formation of cloud and rain. That is why our west coasts are wetter than our east coasts; firstly, they are more mountainous, and secondly, they are exposed to the moist warm ocean winds from the westward and south-westward.

§ 9

Clouds

The water-vapour that is evaporated into the atmosphere manifests itself in many forms other than rain. All the clouds are due to it, for they are nothing but aggregations of excessively

minute droplets of water or crystals of ice, that have condensed out of the air because the latter has become too cool to retain them in the form of water-vapour. Our skies are seldom without a cloud; we watch them with ever fresh wonderment and curiosity. The forms of clouds are endless and ever-changing, but there are certain characteristics which allow them to be grouped roughly into several classes. There are the thin feathery lines and bands of *cirrus,* commonly called "mares' tails," floating nearly five miles high; these are formed of ice-crystals and give rise to many beautiful sights in the sky, such as the wide "rings" round sun and moon, called *halos.* Somewhat lower are the "speckled," "mackerel," and "dappled" skies of *cirro-cumulus* and *alto-cumulus,* the most beautiful of all clouds; we see a wonderful arrangement of orderly and serried ranks. Between broad, straight, parallel bands of snowy-white cloud we have a multitudinous sea of little wavy rippling cloudlets. These often show close "rings" of rainbow colours (coronæ) round sun and moon, and they are generally seen during a spell of fine weather. In place of these types there is sometimes seen the "watery" sky, known as *alto-stratus,* a greasy-grey sky with a patch of pallid light where the sun or moon may be dimly showing; this sky usually follows after the appearance of mare's tail *cirrus* in front of a depression and is practically always succeeded by rain

Thunderstorm and Hail

Lower still, about a mile high, we see the great rolling masses of clouds heaped up in the sky which are called the *cumulus,* the ordinary domed "woolpack" clouds of the summer sky; they are the dark clouds with the silver lining; the cloud is due to moisture carried upwards by ascending air-currents which have been warmed by contact with the ground. Here we have also the heavy grey ragged pall of *nimbus*—the rain-cloud. The gigantic *cumulo-nimbus* or "thunder-cloud" may sometimes grow till it becomes three miles deep from summit to base! It is simply a

dense rain-cloud of the cumulus form. It is very unstable and is the source of all our heavy showers of rain and hail in the summer months. Often it is accompained by storms of thunder and lightning, the latter caused by the disruptive discharge of the electricity that has accumulated upon the raindrops in the cloud, and the former being the audible effect of the discharge. Light travels nearly a million times as fast as sound, and therefore we see the lightning before we hear the thunder; both are, of course, actually simultaneous. Lightning flashes may take place between cloud and earth, and also from cloud to cloud.

There are many clouds in other parts of the world which we have not portrayed here. There is not always a simple answer to the question, why they do this, and why they do that.

> The huge cloud which overhangs a volcano (Humboldt's Volcanic Cloud) as it rolls in huge masses, with the lightning flashing through it, sometimes descends to earth with violence, and rolls down the mountain side with a velocity for which neither gravitation nor wind can account. It so moves because it is *attracted* to the earth, by the direct action of its high electrical charge. In various degrees similar electrical phenomena doubtless play their part in the movements of more ordinary clouds. Again, the gossamer threads of cirrus clouds, the highest clouds of all, sometimes run criss-cross in complex entanglement, and do other things which wind, or wind alone, is not enough to account for. The puzzles which the clouds set us, one way and another, are endless, and our study of them, like that of so many other interesting things in the world, has only begun.

The formation of clouds is not easy to explain; to do so requires on the part of the reader a knowledge of the laws of thermodynamics, and these are rather complex. But anyone can observe the clouds intelligently, and the changes they undergo, and from these changes learn to anticipate the weather that is likely to follow. Such a study will be found as interesting as it is useful.

The Cause of Mists and Fogs

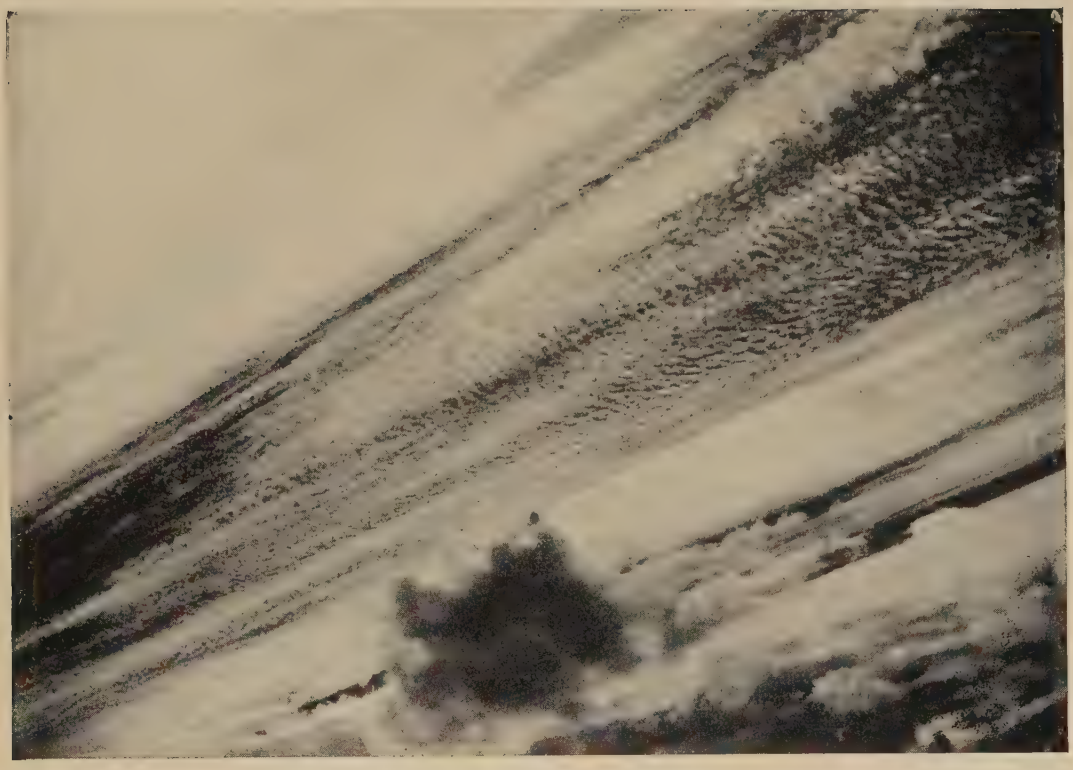
When warm air blows over cold sea the air becomes chilled in contact with the cold water; the water-vapour in the air then condenses out as fog, which is thus really a layer of cloud resting on the earth's surface. In somewhat similar manner, the rapid cooling of the land on a clear night gives rise to valley-mist and dew. In winter-time, when condensation takes place below the freezing-point, we have falls of sleet or snow in place of rain, and hoar-frost instead of dew forms on the ground, while a warm wind setting in suddenly after a hard frost may cover trees and walls with a glassy coating of ice.

Large hailstones, if examined, often prove to be built up of several distinct layers of ice, due to the fact that they are carried up and down many times by the powerful vertical currents of air in the cloud from which they fall, and by this process they receive successive additions of water which become frozen when the hailstone again reaches the higher regions of the cloud.

The atmosphere everywhere contains dust in suspension. Sand blown from the desert, salt from the ocean spray, soot from factory chimneys, ashes hurled from volcanoes, the debris of meteorites, and pollen from the flowers all contribute to form the veil that lies between us and the sun. Were it not for these dust particles in the atmosphere we should never see those gorgeous colour effects that delight the eye. Our azure skies would be almost as black as they are at night, and we should see the sun and stars shining with undimmed lustre; for it is really the dust that produces the lovely limpid blue of the sky. The floating dust particles are exceedingly minute, especially those found in the upper air; they scatter the blue light-rays from the sun, and thus cause the sky to assume the colour that it does.

The Colour in the Clouds; the Aurora

The soft shimmering light of twilight is merely the lingering illumination by the sun of the dust particles in the higher regions



BANKS OF CIRRO-STRATUS CLOUDS WITH CIRRO-CUMULUS CLOUDS BETWEEN, WITH A SMALL DARK PATCH OF CUMULUS THREE MILES BELOW THEM

GOSSAMER WEBS OF CIRRUS CLOUD, HIGHEST UP OF ALL. JUST EQUAL IN HEIGHT ON THE AVERAGE, TO THE SUMMIT OF MOUNT EVEREST

of the atmosphere, and the many beautiful spectacles seen at sunrise and sunset are also due to the diffraction and scattering of the light-rays from the sun. The dust particles and water droplets in the atmosphere have the power of scattering first the blue-violet and then the green components of white light, and so causing the light to change through yellow into red. The glorious tints of the rainbow are due to the reflection and refraction of the rays of light from the sun by the drops of rain, which act like tiny prisms and break up the white light into the rays of varied colours of which sunlight is really composed. But no appearance in our skies can vie in mystery and delicate beauty with the aurora, whose shimmering rays of yellow-green, rose, or crimson light at times transfigure the starlit skies of winter. The aurora occurs some fifty miles up in our atmosphere, and is generally regarded as being due to electrical rays of the nature of the cathode rays which are given out by the sun in greatest quantity at the times of sun-spot maxima. The frequency of auroræ, of sun-spots, and of magnetic storms within the earth show a sympathetic connection with each other, and are in all probability due to the same original cause. Contrary to general belief, the aurora does not presage stormy weather.

§ 10

Periodic Variations

The question is often asked whether our weather is changing for the worse, and to this the answer is in the negative. Very slight variations in temperature and in raininess are known to recur in some places and to have some agreement with the sun-spot cycle of about eleven years, and there have been alternations from dry and warm periods to cool and wet ones, but the periods are very irregular and the changes slight.

The factor that does really make a difference to our weather in Britain is the average position of the cyclone-track during the

year. If the track is more northerly than usual, and passes to the north of Scotland, the year will be brighter, drier, and warmer than normal, because our Islands will then lie more under the influence of the Atlantic high pressure system, but if the cyclone-track lies more southerly than is its wont we shall have duller, colder, and wetter weather than usual.

And very often an abnormal season is followed by one of opposite abnormality. The amazing summer of 1911 with its halcyon days was followed by the dull cold summer of 1912; while the very cold December of 1879 over Europe was succeeded by the mild December of 1880; in central Europe the difference of temperature between these two months was over 20° F. It may therefore be said that the chief characteristic of our weather is rapid variability rather than slow periodic change.

Weather Lore

A good deal of traditional weather lore is familiar to most people, and part of it, at all events, has some scientific basis. There are certain cloud developments, such as those associated with a depression, and which have been already described, that are really accurate guides to coming changes of weather, and there are many reliable maxims in use by sailors, as for instance:

> If the wind backs against the sun,
> Trust it not, for back it will run,

a saying that is quite justified by the behaviour of the wind before a coming cyclone. Such proverbs are based on experience and are capable of scientific explanation. Another adage that "a rainbow in the morning is the shepherd's warning" is also accurate, for it implies that if showers are falling as early as morning-time they are likely to continue most of the day; and this is very likely to be the case, for the rising air currents that form the shower-clouds are not usually effective enough to cause showers until the afternoon. Therefore, if showers are already falling in the forenoon, they are

not likely to cease before evening, and may even continue to fall during night-time.

Halos round the sun and moon are in the majority of cases followed by stormy weather, because the cloud-sheet of ice crystals, in which the halos are produced by the refraction and reflection of the light rays by the crystals, is always found in front of a depression, though it may also occur without the presence of a depression.

Other maxims, again, have considerable value in some localities, but are inaccurate in others. In mountain districts the cloud-cap that forms on the mountain-tops is often used as an indication of the coming weather.

Statements regarding the stormy presage of a red sky in the morning, or of the happy augury of a grey dawn, are not always trustworthy, for their accuracy depends entirely upon the meteorological situation, and a good deal of expert knowledge is required before such signs can be correctly interpreted.

But, on the other hand, some "proverbs" are quite unworthy of serious attention. The effect of the new moon upon the weather, so widely believed in, has been investigated and found to be non-existent. The belief that six weeks of daily rain will follow a wet St. Swithin's Day is equally absurd, for the common occurrence of more frequent rain after that date is due merely to the seasonal change, from the dry early summer to the much wetter late summer and early autumn, to which our Islands are subject.

But the old maxims provide a very interesting study, as those can testify who have read the volume on *Weather Lore,* compiled by Mr. Richard Inwards.

BIBLIOGRAPHY

Clarke, G. A., *Clouds.*
Geddes, A. E. M., *Meteorology, an Introductory Treatise.*
Lempfert, R. G. K., *Meteorology* and *Weather Science.*

McAdie, A., *Principles of Aerography.*[1]
Milham, W. I., *Meteorology.*[1]
Moore, W. L., *Descriptive Meteorology.*[1]
Pick, W. H., *Short Course in Elementary Meteorology.*
Salter, M. de C., *Rainfall of the British Isles.*
Shaw, W. N., *Forecasting Weather.*

[1]These books are American.

XXIV

APPLIED SCIENCE

APPLIED SCIENCE

I. THE MARVELS OF ELECTRICITY

The Age of Electricity

OUR age is the age of electricity. The remarkable revolution which the practical application of electricity has effected in recent years is one of the wonders of modern life. To Electrical Engineering Science the civilisation of to-day owes more than is readily realised. It has solved many great problems which modern conditions of life called into being, and which had to be solved if further progress was to be looked for. Professor J. A. Fleming, who has given fifty years to studying the problems of electricity, has said that the outlook for electrical engineering has vast possibilities "which may materialise at any time and make ancient history of our present achievement," great as that is. The records of the past half-century are wonderful enough; the next fifty years of electricity, it is interesting to learn from such an authority, "is a subject for attractive meditation."

Space and time have been almost annihilated; the transmission of energy, the development of production, and distribution of electrical power all suggest great possibilities. We have seen in previous sections of this work the interesting stage Physicists and Chemists have reached in their investigations into the constitution of the atom, and how these investigations have transformed our fundamental conception of matter. The discovery of the electron as a mobile constituent of the atom of matter has, Sir Ernest

Rutherford says, exercised a wide influence on electrical theory, and has been the starting-point of attack on numerous electrical problems. Long before this discovery electricity had become our handmaiden; it was a mysterious force, the nature of which was little understood, but we now know a great deal about the old-time mysterious forces of electricity and magnetism.

The revolution which has been accomplished in modern life by electricity has been so quietly effected, so steadily cumulative, so all-embracing that the ordinary man, perhaps, fails to appreciate the scope and the majestic proportions of the work of modern electrical engineering science. A cinematograph picture that would contrast things as they were done only fifty years ago, with the same things done by means of electricity to-day, would strikingly illustrate the triumphs of applied electricity. The Institution of Electrical Engineers celebrated its Jubilee in March, 1922; less than fifty years ago the electrical engineer was looked upon as a glorified showman, displaying his wares from town to town. Sir Alexander Kennedy, at the meeting referred to, recalling the electrification of the Houses of Parliament in 1890, said he remembered an urgent request that an effort should be made to keep the lights steady, "especially during the Speaker's dinner." Sir Oliver Lodge described the impetuous course of the first British electric tram, "which came to rest in a shop window." Godalming was the first town to be lighted by the Swan lamp, and Mr. S. Evershed related how "the supply cables were laid, in innocence, in the open gutter."

The present generation has grown up with the ever-evolving wonders of electricity and has probably ceased to wonder at them. The majority of persons know next to nothing about electricity, and few could explain the principles that underlie the generation, transmission, and utilisation of electrical energy. It would be a task even to enumerate the various spheres of the wonder-working activities of electrical power. It will drive the transcontinental express up the dizzy heights of the Rocky Mountains; it will haul

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THOMAS A. EDISON

The famous American electrical engineer and inventor, who began life as a railway newsboy. Among non-electrical inventions we owe him the phonograph and the cinematograph. As an electrician he produced the first satisfactory glow-lamp, improved dynamos, and telegraphic and telephonic apparatus, and invented the nickel-iron storage battery.

Reproduced by permission from "The Romance of Modern Electricity" (Seeley, Service & Co.).

AN ELECTRIC COAL-CUTTER

Many millions of tons of coal are "won" annually with the aid of mechanical cutters driven by electric motors, the output per machine ranging up to 15,000 tons in the twelve months. The machines are of several types, some of them designed for working in very confined spaces where a miner could wield his pick only with difficulty. The upper illustration shows a cutter in place, and miners peering out near its ends. The machine itself is seen in the lower photograph, reproduced by permission of Messrs. Mavor & Coulson, Glasgow. The long bar on the right which does the cutting is studded with short picks, and is rotated and oscillated to and fro at the same time.

trains of 800 tons weight over the mountain ranges of the Alps; it will flash its wireless messages across the Atlantic at the speed of 186,000 miles a second; it will supply all the light and heat the greatest city could want. Long submarine electric cables connect the most distant lands, but such cables become more and more dispensable. You can converse with a person in Paris without using wire or cable; you can talk to an air pilot hidden behind the clouds.

Some of our greatest industrial undertakings are solely devoted to Electrical Engineering practice, and in almost every phase of industry it plays a part: in the coal mine we have electric coal-cutters, haulages, and winding machinery; in the modern iron foundry the electric furnace which will produce temperatures up to 6,000° F.; in the Engineer's shop the electric arc for welding all manner of metals and alloys.

In factories steam power and the mechanical transmission by shafting and belt is almost displaced by electric motors driving separate machines, or groups of machines; and even for the propelling of ships, electric energy transformed from the mechanical energy of the steam turbine has been applied successfully. We cook by electricity, do our laundry-work by electricity, sweep our rooms by electricity, even the dentist's tiny drill is whirled round by electricity. We have electro-magnets, powerful enough to lift ten tons of scrap iron; the medical man may use a magnet to extract fragments of steel from a workman's eye.

Ease of Transmission

The cause of the enormous vogue of electrical power is to be found in the fact that energy can be transmitted and distributed in its electrical form very cheaply and efficiently. Where distances are considerable, electricity has the field to itself. If a large amount of energy has to be transmitted to a point, say, 100 miles away, the alternatives are: air under pressure, water under pressure, and electricity. For the first would be required huge pipes,

expensive to make, lay, and maintain; and, in spite of the greatest care, these pipes would be sure to leak and a large amount of power would be dissipated. Hydraulic transmission would also need very large pipes, buried deep to escape frost. For carrying the energy as electricity, small insulated conductors buried in the ground, or carried aloft on poles suffice. The conductors may change direction suddenly, twisting and bending about to suit natural conditions, without the loss of efficiency which inevitably would result in the case of pipes carrying fluids. Rivers, wide chasms, and other natural obstructions present difficulties not comparable with those encountered by a pipe line, as the conductors negotiate them in huge spans.

Cheap and efficient transmission, then, makes it possible to generate current in bulk at centres where conditions are favourable for generation and to deliver it over large areas at a lower price than it would cost if generated in small quantities on the spot. The energy converted may be either that of fuel capable of transport—such as coal or oil—or, again, that of waste gases or falling water, which can be converted profitably only where available. As for coal, under certain conditions it may be more economical to move it to where energy is wanted, than to transport current; but it cannot be denied that judiciously distributed central power stations produce a given amount of power much more cheaply than a multitude of independent plants. For railway working, 2 lb. of coal consumed in an electric power station will do the work of 5-7 lb. burned in a locomotive. On the other hand, the energy in the waste gases from a blast furnace or in natural heat must be converted on the spot or not at all. Hence many smelting plants become centres from which electric power is distributed in all directions—as much as 4,000 h.p. being obtainable from one furnace—and places where terrestrial heat is available in sufficient quantities acquire a new importance. Thus, at Lardarello in a volcanic district near Volterra, Italy, subterranean steam is brought to the surface in pipes and made to generate 10,000 elec-

trical horse-power, for transmission to Leghorn, Florence, and Pisa, to which points the steam itself obviously could not be piped.

§ 1

What a Current of Electricity is

What we know to-day of the nature and inter-relationship of electricity and magnetism has been explained in a previous chapter. The electro-magnet, in some form or another, is the basis of all machines for generating electric currents by mechanical power called dynamos, of electric motors, induction coils, and other appliances. The electro-magnet is at the bottom also of all modern electric telegraphy and telephony.

It was the crowning discovery of Michael Faraday that a current of electricity could be induced in a closed coil or ring of wire by moving it towards or away from a magnet—in other words, by moving it across a magnetic field. Faraday was also responsible for the first dynamo. What is a magnetic field? An electric current is a flow of electrons, passing from atom to atom. If we put zinc and copper together we get a mild current of electricity; the atoms of zinc are particularly disposed to part with their electrons, and these electrons pass to the atoms of copper; their passage is a "current"—an atom is giving up an electron to its neighbouring atom. If the metals copper and zinc are immersed in certain chemicals, which slowly dissolve the zinc, and the two metals are connected by a copper wire, the current is stronger, there is a brisker flow of electrons (see p. 270). Copper, in other words, is a good "conductor." Now we have also seen (p. 273) that there is no movement of electrons without their creating an attendant field of energy; a magnetic force due to the electric current exists in circles around the wire, and results in an ether disturbance, or strain. Thus the space around the path of an electric current is filled with lines of magnetic force, and we have what is called a "magnetic field."

Faraday therefore found the means of creating an electric

current by causing a coil of insulated copper wire to spin round between the ends or poles of a horseshoe-shaped magnet. He gave us the first magneto-electric machine, developed now to such wonderful extent.

> Every taxicab, motor-bus, or motor-vehicle contains a Faraday magneto, used to make the electric spark which fires the charge of petrol vapour and air in the cylinder. Every gigantic dynamo in our electric lighting or power stations is only a descendant of that first rudimentary magneto machine which Faraday made by spinning a circular copper plate between the poles of a powerful magnet in the laboratories of the Royal Institution.

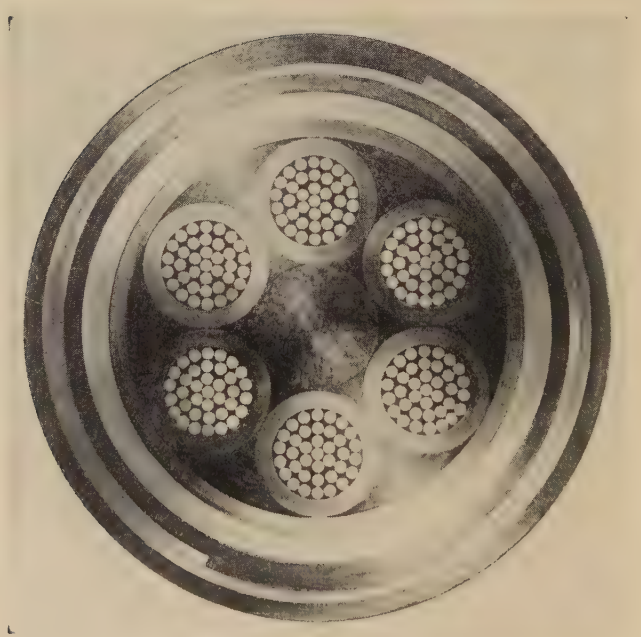
The simplest illustration of how an electric current is induced in a wire is to take an ordinary horseshoe-shaped magnet, which everyone has seen, and with the horns kept upright, move a section of a copper wire ring up and down between the poles—the horns, that is—when an electric current is induced in the wire ring.

As has been said, round the poles of the magnet there exists a state of electrical strain, a "magnetic field." When the wire cuts this, electrons pass freely and with incredible rapidity from one atom of the copper wire to the next—electricity is generated. The same thing would happen were the ring stationary and the magnetic field moved across it; the essential factor is movement of the one thing relatively to the other. The direction in which the electric current flows depends on the direction in which the wire moves. During the upward movements the current rushes one way through the circuit, i.e., the ring; during the downward movements the current travels the opposite way. Such a current is therefore called *alternating,* since it takes either direction only during alternate movements of the conductor. This simple illustration explains the general principle, and it was from such a discovery, as we have said, that Faraday constructed the first dynamo for the generating of electricity.

Reproduced by permission of the Commercial Cable Company.

LAYING A SUBMARINE CABLE

The illustration shows one of the shore ends of the New York-Newfoundland submarine cable. After being brought ashore a cable is laid in trenches as far as the cable station, where it is connected up with the usual type of overhead telegraph lines. This illustration shows the cable being carried up the cliffs at Cuckold Cove, Newfoundland, by a large number of men, each bearing the weight of a few feet. The largest type of submarine cable yet made weighs 62 ½ tons per mile, and was designed to resist the crushing strain of icebergs grounding in shallow water.



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SECTIONS OF ARMOURED CABLES FOR THE CONVEYANCE OF ELECTRIC CURRENT UNDERGROUND

The conductors, of tinned copper wires stranded together, are insulated with waxed paper or rubber tape, jute soaked in tarry compounds, vulcanised bitumen, or other substances. A sheathing of lead, which appears in the illustration as a continuous white ring about ⅛ in. wide, is added by passing the cable through a lead press which squeezes out the lead round it as a continuous shell. This effectively keeps out moisture, but, being easily damaged, is protected outside by jute wrappings and an armour of galvanised iron wires (top) or interlocking steel tape (bottom), which is again covered with a serving of jute.

The Generator

Briefly, a generator consists of a coil or coils of wire, wound on a soft iron core to form a drum-like armature (as it is called); while the permanent magnet becomes an electro-magnet, or a number of electro-magnets, capable of creating very powerful magnetic fields. The armature is mounted on a shaft or spindle and revolved at high speed between the magnet poles; or it may be stationary, the magnets revolving round it. It should be noted that the armature coils do not represent our original wire ring completely, as they form only part of the circuit, the main part of which would consist of stationary wires leading the current wherever it is needed. If the armature itself revolves, it must be put in communication with the stationary part of the circuit by means of brushes—flat pieces of metal or blocks of carbon—which press upon smooth rings connected with the armature coils and revolving with them.

Such a machine may be compared to a cylinder having its ends connected with the ends of a pipe. Just as a pump piston, moving to and fro in a cylinder, forces water to and fro through the pipe, so the generator drives electrical energy backwards and forwards through the conducting circuit, the reversals of direction occurring many times a second.

We may say here that for some purposes alternating current is not convenient. The term dynamo is commonly reserved for a class of generator which is so designed that it pumps current continuously in the same direction through the circuit. The current is then said to be "continuous," or "direct." In dynamos the armature is invariably the revolving part. The brushes which connect it with the circuit do not in this case press on separate rings, but on a single cylindrical drum, revolving with the armature and divided lengthwise into a number of insulated segments, each connected with some of the armature coils. The brushes make contact with it at points half a circle apart, so that if there be, say, twelve segments, they will be in contact with Nos. 1 and

7, or with Nos. 2 and 8, and so on, at any one moment. As it is impossible to go into further details here, it must suffice to say that the rotation of the commutator, as the divided cylinder is named, causes the pairs of segments successively to come against the brushes at the instant when otherwise reversal of flow would occur, and prevent reversal in the stationary part of the circuit by linking each brush with a coil in which current is travelling in the desired direction. To revert to the coil and permanent magnet illustration, the effect is equivalent to turning the coil over between movements, so that the same face of the coil cuts the field every time.

Electric Circuits

A current of electricity to be maintained requires of course a complete circuit, that is to say, a current only flows between two poles, just as a current flows from the zinc element of an ordinary primary battery through a wire back to the carbon element; if the circuit be cut, the current stops. To take the case of a generator with an outside circuit. It delivers current to the circuit through one brush, and receives it again through the other brush; that is, assuming the circuit to be complete. If there be a gap in it anywhere—if the circuit be "open"—the conditions necessary for electric induction are not fulfilled, and the armature will revolve easily and idly, generating no current but remaining in a state of excitation only. Directly the circuit is completed, however, current flows through it, its amount increasing or decreasing with the speed at which the dynamo is driven. If speed were allowed to increase indefinitely the friction might ultimately cause the conductor to heat up to melting-point. An ordinary "circuit" is normally in a "broken" or incomplete condition. The fixed conductors which form part of it are near each other, so that connection may be made between them where desired. On an electrified tramway one conductor is represented by an overhead insulated wire, and the other by the rails which act as "earth" and

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A MARVEL OF POWER TRANSMISSION BY OVERHEAD CONDUCTORS

The 60 conductors seen make up 20 three-phase circuits, transmitting between them 200,000 horse-power at a pressure of 10,000 volts. The bare conductors are insulated from the supporting steel trestles by large porcelain insulators of very high resistance. In this case they are of aluminium, a metal which is widely used for transmission lines. Current is now transmitted at pressures up to 220,000 volts, and for power purposes over distances of up to 200 miles.

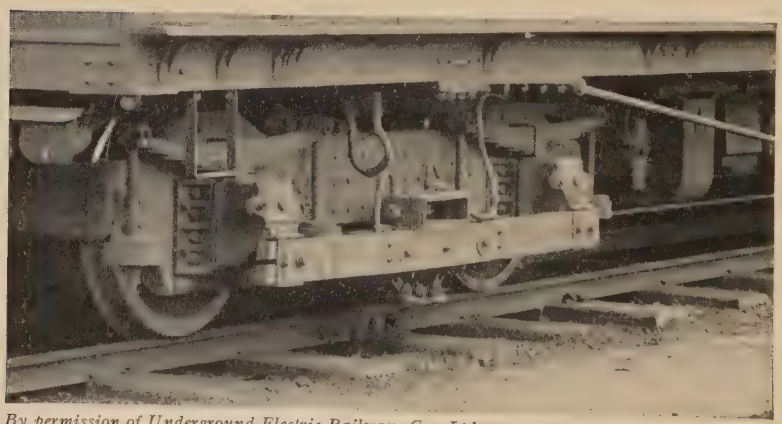
Reproduced by permission from "Fifty Years of Electricity" (The Wireless Press, Ltd.).

A COPPER RING HELD OVER THE POLE OF AN ALTERNATING CURRENT ELECTRO-MAGNET IS STRONGLY REPELLED AND JUMPS UP IN THE AIR WHEN RELEASED

From the "Romance of Modern Electricity" (Seeley, Service & Co.).

A VIVID FLASH OF FORK LIGHTNING TAKEN OVER HOUSE-TOPS

The lightning discharge is exactly similar to the spark from an electrical machine, but on an immensely grander scale. Lightning is but an electric spark which may be miles in length: it passes between cloud and the earth, or from cloud to cloud. A well-known authority has estimated the average duration of a flash as five-millionths of a second, and its average power at 25,000,000 h.p.



By permission of Underground Electric Railways Co., Ltd.

HOW AN ELECTRIC TRAIN PICKS UP CURRENT

Touching the rail between the wheels is seen a cast-iron shoe, with curved-up ends, which is dragged along in contact with the rail. Current enters the motors through similar shoes touching an insulated rail (not visible) between the tracks. The current then passes out through the shoe shown to the running rails, which are bonded together to act as return or negative conductor.

bonded conductors back to the source of supply. In itself an insulated conductor carrying current is not dangerous. A bird may perch on it with immunity, and men who repair the overhead wires of tramways handle them safely with bare hands, because the platforms on which they work are insulated from the ground. But if a person touches both the insulated conductor *and* the earth or the other conductor, he completes the circuit, and may be killed at once.

In continuous-current circuits for traction purposes it is usual to insulate the positive conductor, and use the rails as the "return" or negative conductor.

§ 2

Generating Power Stations

Before considering how electrical energy is transmitted and distributed from the generating station to the points where it is required, let us see what goes on at one of the great electrical power-stations. As a general rule they do not convey to a visitor, who is no expert, any adequate impression of the scale on which such vast energy is being produced. There is no bustle and little visible movement, and not much from a spectacular point of view to excite one's wonder. The three principal central power-stations in London are at Chelsea, at Wood Lane, and at Neasden. From these power-stations the various underground railways receive the electrical energy which enables them to transport 571 million passengers a year. An enormous volume of fuel is required; one station alone consumes no less than 260,000 tons of coal per annum for the production of electric current.

We shall see great steam turbines driving huge dynamos and alternators. At the Chelsea Power Station the power is equal to 78,000 kilowatts, or about 100,000 horse-power. Current is supplied from these to twenty-seven sub-stations scattered about London; at these sub-stations the power is transformed into

direct current to feed the live rails of various underground and electric railways and tramways.

Distribution of Current

Current is usually generated in its alternating form, at a pressure of 3,000 volts upwards. A volt, it should be explained, is the electrical counterpart of the "pound per square inch" used to describe the pressure of gases or liquids. To one side of the power-house, perhaps in a separate chamber, will be found the switchboard on which are mounted electrical gauges for measuring the condition of current, and handles for operating the switches whereby current is controlled and directed.

Where the generators are many in number, they may be divided into groups, each having its own switchboard. Just as the units of a battery of boilers contribute through their individual branch pipes and valves to a main steam pipe, so the generators of a group feed a set of short collecting conductors, called 'bus bars, through switches on the switchboard.

By means of other switches the 'bus bars can be linked with one or other of the sets of conductors which carry the current away from the power-house for distribution; and, where there are several groups of generators, provision is made for cross-connecting the several groups enabling them to come to one another's aid when necessary. The switchboards collectively may be compared to the bridge of a ship; they are the centre from which the brain and hand of the operator direct the mighty forces seeking an outlet. The movement of a lever may send current representing thousands of horse-power to a point within sight of the power-house, or start it on a journey of hundreds of miles.

Current intended for local distribution may be turned into the mains straight from the generators, to be modified subsequently as will be described later. On the other hand, it may first be sent to transformers, by which its voltage or pressure is increased or stepped-up, as electricians say. The loss in trans-

Reproduced by permission from "The Romance of Modern Electricity" (Seeley, Service & Co., Ltd.).

A UNIQUE ELECTRIC RAILWAY

Part of the Barmen-Elberfeld Railway, Germany. From end to end the track is supported by frames, set about 30 yards apart, straddling the Wupper River and town streets. The carriages are suspended by large hooks from electrically driven bogies running on the track. A carriage accommodates 50 passengers, and when fully loaded weighs about 14 tons. The railway is 8¼ miles long, and speeds of up to nearly 40 miles an hour have been attained on it.

Photo: W. H. Mack, Runcorn.

ELECTRIC TRANSPORTER BRIDGE

This bridge, the largest of its kind, crosses the Mersey and the Manchester Ship Canal, and has a span of 1,000 feet between centres of towers. The car seen close to the nearer tower is suspended by cables from trolleys running on the bottom flanges of the girder. The electric motors which propel the trolleys are under the control of a man in the small cab on the top of the car. Up to 600 people can be transported at a time from one end of the bridge to the other in about two minutes.

By permission of Underground Electric Railways Co., Ltd.

INTERIOR OF LOTS ROAD POWER STATION, CHELSEA

This station, which covers four acres of ground, supplies current for operating the Metropolitan District and all the tube railways of the Metropolis except the Central London. The equipment consists of ten generators (eight of which are seen in the photograph) driven by Parsons steam turbines and giving a maximum total output of about 80,000 kilowatts (107,000 horse-power). Alternating current is generated at 11,000 volts and distributed to sub-stations, where it is converted into direct current at 600 volts for the train motors. Automatic machinery raises the coal (260,000 tons of which are burned annually) from barges to overhead hoppers and feeds it to the boilers.

mission due to the resistance of a conductor decreases rapidly with increase in pressure; or, to state the facts differently, the higher the pressure the smaller may be the conductor for an equal loss. The cost of conductors is a very heavy item, so pressures have been raised again and again with increase in distance of transmission. Twenty years ago 50,000 volts was considered a very high pressure; to-day lines are carrying current at 220,000 volts, and electricians look forward to much higher voltages still.

After leaving the step-up transformers, the long-distance current flashes through insulated wires or cables, slung aloft on poles and trestles, and after a journey over, maybe, rivers, mountain passes and gorges, prairies and deserts, reaches the far-away station where it is to be distributed. Before admission to the switchboard it has its pressure reduced, by step-down transformers, to a suitable level. The switchboard divides it among a number of different circuits. Some may be sent to sub-stations, where it is converted into continuous current for operating tramways and suburban railways. (Machines of the kind which effect this conversion may be heard buzzing in annexes to some of our tube stations.) Other circuits supply power for running factories; and others again, through small transformers dotted about over the area served, energy for lighting and heating. At any of its many final destinations the current may of course be passed through apparatus to suit it for any special purpose.

§ 3

The Storage of Electricity

The only method yet discovered of storing electrical energy in commercial quantities involves the use of accumulators or storage batteries, subdivided into a number of cells. In a cell are a number of plates or elements charged with chemicals and submerged in a liquid called electrolyte. The plates are interconnected to form two groups, those of one group alternating with those of the other group; and each group is connected with

a terminal. If continuous current from an outside source be sent through the cell, certain interactions take place between the plate chemicals and the electrolyte, and electrical energy is converted into chemical. The cell thus becomes in effect a primary battery willing to reconvert its chemical energy into electrical if the current be allowed to pass through a circuit in the *reverse* direction to that of its entry, and the chemicals to revert to their original condition. The amount of energy that can be stored in a cell depends on the size of the plates; and, while the electrical pressure or voltage of a single cell is strictly limited, any pressure is obtainable by connecting together in series a sufficient number of cells.

In the past storage batteries as a class have suffered from several disadvantages, the most serious of which were their great weight relatively to capacity and the slow rate at which they could safely be charged and discharged. Recently, however, some important improvements have been made, which promise reductions of weight and charging time so great as to give an enormous impetus to the use of the independent accumulator-and-motor vehicle, which has some strong points in its favour, but has hitherto been restricted in radius of action and speed. With the new batteries a journey of 150 miles or more before recharging should be possible, and recharging be a matter of but a few minutes, instead of hours. Even on the railway the new accumulator may bring interesting developments. A 90-ton battery is estimated to have a capacity of 8,000 horse-power—equivalent to 1,000 horse-power exercised continuously for eight hours. This energy would take a train from London to Edinburgh at express speed.

§ 4

Electric Traction

An electric train or train hauled by an electric locomotive has a great advantage over the ordinary steam train, in that it gets into its stride much more quickly. A steam train starting

Reproduced by permission of J. Jackson & Sons, European Agents for the Chicago, Milwaukee, and St. Paul Railway.

SIXTEEN MILE CANYON, MONTANA

A scene on the Chicago, Milwaukee, and St. Paul Railway, the largest electrified railway system in the world, running practically across America. It crosses four mountain ranges—the beautiful Belt, the mighty Rocky, the forested Bitter Root, and the snow-crowned Cascade Mountains.

from rest increases its speed by from two-fifths to half a mile per hour every second; whereas an electric train accelerates from a mile to a mile and a third per hour per second, and at the end of half a minute will be travelling at 30 to 40 miles per hour. This quick acceleration is exactly what is wanted in urban and suburban areas, where stops are frequent and traffic heavy, as it means a much higher average speed, shorter intervals between trains, and a great increase in the carrying capacity of a line. Actual figures show that schedule speeds on lines converted from steam to electric traction have risen by 20 to 50 per cent. During its operation by steam the London District Railway carried a maximum of eighteen trains per hour on a track, whereas the present electric trains run at intervals of about one and a half minutes, or forty-two in the hour, at the busiest times of the day.

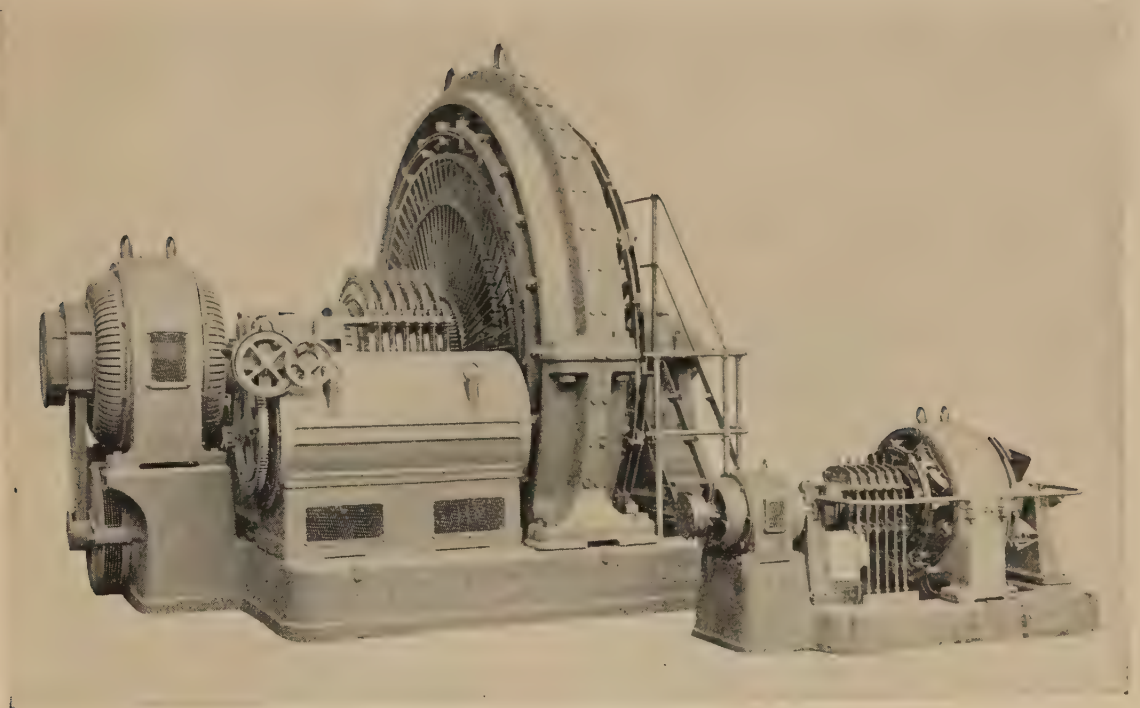
The suburban electric train dispenses with a separate locomotive, because the motors driving it are distributed among the coaches. There are usually two motors, each of 200 horse-power, under every other coach, so that a six-car train has a propelling power totalling 1,200 horse-power. The distribution may be even more generous, but in any case the electric train is more highly "powered" than the steam train of equal length, and it must be so to negotiate at high speed the heavy gradients which engineers nowadays do not hesitate to include in an electrified track, though they would be rigorously excluded from a new steam-operated railway. The multiple-unit system, as it is called, of train control enables any number of coaches to be coupled together without reducing speed capacity, as each unit contributes its proper proportion of power. At the same time all the motors are as fully under the driver's control as they would be if concentrated in the locomotive.

Powerful Electric Motors

A very large part of the electrical energy generated by the machines ultimately finds its way to electric motors, whereby it

is reconverted into mechanical energy and made to do work. Thanks to the ease with which the electric motor can be connected to an electric circuit, to its cleanliness, compactness, and generally accommodating nature, it finds countless uses, which are being added to every day. In size and power the electric motor ranges from the tiny units attached to the dentist's drill, the desk fan, or the carpet-sweeper, to the great machines which drive rolling mills and propel huge ships. It has given navigators the revolutionary gyroscopic compass, which remains quite unaffected by the proximity of iron and steel. In mines it cuts, ventilates, drains, and hauls, penetrating whithersoever a man can go. Attached to pumps, it accompanies the diver into the holds of ships; during the war the submersible electric pump kept afloat many ships that without it would have foundered, and then and since has brought many sunken ships back to the surface. In the gold-mines of the South African Rand great economies have been effected by installing electrically-driven turbine pumps at the bottom of the shafts to force water to the surface—in one case through a sheer half-mile.

In California, electric motors developing 190,000 horse-power are used in agriculture alone, and the rice industry is almost entirely dependent on irrigation by electrically-driven pumps. In many factories complicated systems of belts and shafting have given way to motors connected directly to machine tools. The electric crane toys with loads up to a hundred or more tons. The electric navvy scoops up several tons of earth or broken rock at a bite, two or three times a minute. Electric windlasses work the largest ships easily through the locks of the Panama Canal; and haul boats, trains, and waggons up inclines. Electric traction, which has revolutionised transport in many respects, and thereby affected our daily lives to no small extent, is based on the electric motor. In short, wherever motion is required the electric motor is, if possible, pressed into service.



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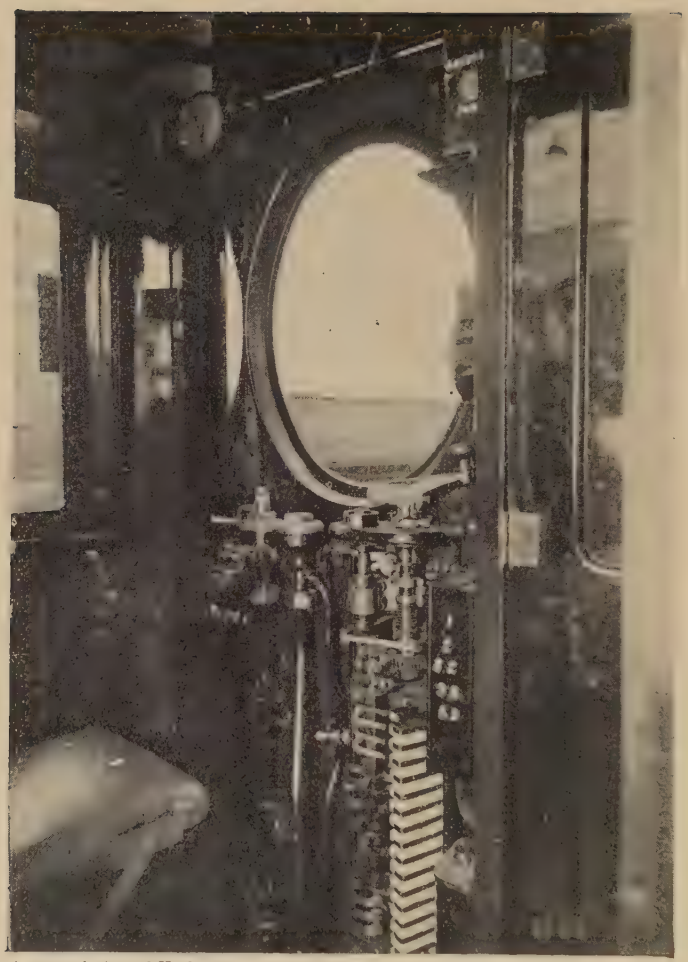
ROTARY CONVERTERS

Electric energy is commonly generated in power-houses as alternating current, which is distributed *at high pressure*. In order that such current may be utilized by the direct-current motors propelling electric trains and trams, it must be converted into continuous current. It is therefore sent through machines called rotary converters, after being reduced to the required pressure by transformers, in sub-stations at various points in the area supplied. Our illustration shows a large and a small converter of 3,000 and 300 kilowatt capacity respectively.

By permission of the Chloride Electrical Storage Co., Ltd.

STORAGE BATTERIES OR ACCUMULATORS

An installation like the above is found in many electrical power generating stations, where it fulfils the same functions as a gas-holder at a gas works. Surplus energy is stored in the accumulators, so that the reserve is available when the demand on the station is greatest, and in case of breakdown. It may even take over the whole duty of the station at times of light load, to give the generating plant a rest.



By permission of Underground Electric Railways Co., Ltd.

"THE DEAD MAN'S HANDLE"

A view of the interior of the driving cab of an electric train, showing the controller (with casing removed) and the handle at the top which corresponds to the regulator of a steam locomotive. It is called the "dead man's handle," from the fact that if the driver loses his hold through illness or for any other reason the handle automatically springs back and the current is cut off from the motors and the train brakes are applied. This precaution contributes greatly to the safety of the passengers.

§ 5

Big Electrical Feats

In Great Britain the electrification of main railway lines is in its infancy. On the Continent and in the United States it has been developed considerably. Switzerland, Austria, and Italy are electrifying long stretches of their railways, and tunnel sections through the Alps have been worked by electric locomotives for some time past. The longest "all-electric" runs are in the United States, and electrification is revolutionising heavy haulage: trains of 5,000 tons are handled in easier sections, and even heavier combinations are foreshadowed.

Naturally, America has most to show in the way of mammoth electric locomotives and the biggest electrical engineering feats. Here physical and other conditions demand engines of great power. We have heard a great deal about the mighty steam Mallet locomotives, some of them weighing over 400 tons, but not so much about their electric rivals.

Some time ago a unique contest between steam and electricity was carried out at Erie. Two powerful modern steam-engines of the class used for hauling the big "limited" trains on the New York Central Railway were linked together and pitted in a pushing match against a single electric locomotive, designed for similar service on the most westerly section of the Chicago, Milwaukee, and St. Paul Railway. The electric pusher was driven backwards some distance without opposition, but when current was switched into its motors the steam-engines were gradually brought to a stop and then made to retreat in a regular rout, with throttle still full open. Surely an omen of the future!

The tests included another of great interest. The electric locomotive was driven ahead for a time by the others, then it was called upon to check them, which it did by simply reversing the motors so that they acted like dynamos and pumped power *into* the conductors and back to the power-station, the contribution amounting at times to over 2,600 horse-power.

In America great stretches of main lines have been electrified and are worked by electric passenger and freight locomotives, of up to 4,000 horse-power. The feats performed by some of these monsters in mountainous districts are indeed astonishing. On the Norfolk and Western Railway coal trains of 3,250 tons are taken up 2 per cent. grades by two electric haulers at double the speed previously attained by three of the largest Mallet steam locomotives. This is but one instance out of many that could be quoted. The secret of the electric locomotive's colossal strength is of course that a very much larger percentage of its total weight can be devoted to the apparatus that gives rotation to its wheels, since it draws its energy from an outside source instead of from a ponderous boiler.

Climbing the Rocky Mountains

The longest stretches of main line yet electrified are on the Chicago, Milwaukee and St. Paul Railway, the most recently completed of the "Transcontinentals." One of these, the Rocky Mountains section, is 440 miles long; and the other, the Cascade Mountains section, from Othello to Tacoma, 211 miles long. The gap of 200 miles on the flatter country between them will in due course be electrified also, and a continuous run of over 800 miles by electric power be possible. These sections include many long and severe grades, sharp curves, and many tunnels, and generally taxed steam traction to the utmost, especially in winter, when the steam trains were liable to get frozen up during enforced halts. Running times have been cut down by one-third since electrification.

The sections are supplied by several power-houses with current transmitted as alternating current at 100,000 to 110,000 volts to sub-stations distributed at intervals of about 30 miles along the line, where it is stepped-down and converted into 3,000-volt direct current for feeding to the overhead conductors. The same general principles are adopted for most electrified railways, though the pressures and distances may be different.

ELECTRIC TRAINS THROUGH THE ALPS

Since the St. Gothard Railway exchanged steam for electric traction the passage of the 9-mile tunnel through the Alps has been rendered a much more speedy and comfortable business. The locomotive emerging from the tunnel is a Brown-Boveri with four 450 horse-power motors. It is able to haul a 300-ton train up a grade of 1 in 38 at speeds up to 30 miles an hour, and to develop 2,500 horse-power for short periods. Traffic through the Simplon Tunnel, 12 miles long, has been worked electrically since shortly after the completion of the tunnel in 1906.

By permission of J. Jackson & Sons, European Agents for the Chicago, Milwaukee, and St. Paul Railway.

ELECTRIFIED YARDS AT BUTTE, MONTANA

A scene on the Chicago, Milwaukee, and St. Paul Railway. At this great mining centre all the shunting in the freight yards is done electrically. Overhead are seen the conductors, suspended from strong catenary cables, which in turn are carried by other cables spanning the yards and supported on strong poles. Current, generated in hydro-electric stations and transmitted at 110,000 volts pressure, is converted, in sub-stations distributed along the railway, into direct current at 3,000 volts for the locomotives. The great success attained by electric long-distance haulage on this system inaugurates a new era in railway history.

It is interesting to note here that the power needed to pull trains up the slopes of mountains in some places is now so largely supplied by the weight of water falling down in other places. What may be called a balanced lift effect is produced through the medium of the water turbine and the power-house. Swiss waterfalls, in this roundabout fashion, move trains through summit tunnels, and carry them up high peaks even to within a few hundred feet of the Jungfrau's crest. By a lavish snow- or rainfall at high elevations, nature atones in many countries for the absence of fuel. Now that man knows how to use it, "white coal" is able to replace black.

People whose experience of electrified lines is limited to suburban tracks may regard electric haulage as slower than steam. It may, therefore, be pointed out that the highest speed ever attained on a railway—131 miles per hour—was made by an electric locomotive as long ago as 1903. The conditions certainly were abnormal, as a special track had been prepared; so to set any doubts at rest it should be added that, where main lines are operated electrically, express speeds are around 60 miles an hour, or as high as are permissible on an ordinary track worked under economical conditions.

Where coal has to be used as the source of power there is no question about the economy in fuel given by electrification. The amount saved in a year by the Transcontinental railway referred to on its electrified sections would, according to an authoritative statement, suffice to move 270 ocean liners, each of 13,000 tons displacement, from the United States to France and back again.

§ 6

Electricity from Waterfalls

The utilisation of water-power on a large scale in the production of electrical power is made possible by the dynamo and electric motor. We have only to go to the famous Niagara Falls

to witness the conversion on a large scale of the energy of falling water into electrical power; there, within a space of a few square miles, are to be found more generating stations operated by water than in any other equal area of the earth's surface. The conditions are ideal. The Niagara River, connecting Lake Erie with Lake Ontario, falls through a vertical distance of over 330 feet during a few miles of its course, including the sheer drop of 159 feet of the Falls proper. Every second, more than 220,000 cubic feet of water plunge over the rocky ledge into the whirlpool beneath. A simple mathematical calculation will show that the potential energy of this fall and flow combined represents about 8,000,000 horse-power.

During the last twenty years several generating stations have risen successfully beside the Niagara River, some of them above and others below the Falls; sufficient water is now deflected from the last—without injury to their beauty—to supply the neighbourhood and towns within a radius of 100 miles with a bountiful and cheap supply of electric current. Already the Falls of Niagara alone furnish half a million horse-power for lighting and traction to Canadian and American cities; when the full programme is completed the amount will be doubled.

The visitor unversed in engineering science might expect to find at Niagara enlarged editions of the water-wheels which are picturesque features of many of our streams. As a matter of fact, there is not such a wheel to be seen, the water motors used —turbines—are hidden away under the roofs of the power-houses. Each of the eight plants has its distinctive characteristics, but they all depend on certain principles: drawing power from an upper level, leading it down to a lower level through great steel tubes called penstocks, passing it through turbines, and finally discharging it into the river below the Falls at a velocity much less than it would acquire in a straight drop through the same distance.

In order to get a sufficient fall, the Niagara Falls schemes

included the sinking, through the rock, of great vertical rectangular pits, 150 or more feet deep, at the bottom of which turbines are located, and the driving of long tunnels to carry the water away from the pits after it has done its work in the turbines. The penstocks feeding the latter are attached to the sides of the pits, and the turbines are connected by long shafts with the rotating parts of their respective generators in the power-house far above.

Great Engineering Feats

It is impossible to even mention here the many great engineering feats performed at Niagara in connection with the various power schemes, but passing reference may be made to two notable discharge tunnels driven 7,000 and 2,000 feet respectively through the rock. The former is reputed to be one of the largest tunnels in the world as regards size of section, and it is otherwise interesting as having its exit behind the water curtain of the Canadian Falls. Taking schemes separately, the latest is undoubtedly the most imposing, as it makes use of a total fall of over 300 feet, or about twice that utilised by most of the earlier installation. The Falls are in this case "turned" by a canal, 12½ miles in length, which draws water from the Welland River entering the Niagara River a long way above the Falls, and leads it to near Queenston, below the lower rapids, where a huge power-house is being erected at the water's edge. This will ultimately contain ten units of 40,000 electrical horsepower each. The construction of the canal required the excavation of over 13,000,000 cubic yards of material, mostly rock; and so great is the flow through the new channel that the current in the Welland River has been reversed beween the junction with the Niagara River and the entrance to the Canal.

How Water Turbines Work

We can give here only a brief description of the water turbines used at Niagara. The type mounted at the bottom of the

deep pits there, referred to in an earlier paragraph, has a large upright barrel-like fixed chamber into which the penstock (steel tubes) delivers the water under high pressure; and a vertical shaft passing through the ends of the barrel, with two large disks attached to it of larger diameter than the barrel. The disks are outside and almost touching the ends, and round their circumference are attached upright rings of vanes which overlap the barrel, so as to be opposite rings of guide blades fixed in openings near the barrel's ends. The water gushing outwards through the guides strikes the wheel vanes at an effective angle and drives the disks round and round, and the shaft with them. Outside the moving vanes are solid rings which can be raised or lowered by an automatic governor to regulate the rate of escape of the water and the speed at which the turbine runs.

The turbines in the power-houses below the Falls are differently arranged. They stand beside the generators on the same floor, and their shafts are horizontal and short. The water enters a ring-shaped chamber, open on its inner side, and passes through guides on to the blades of an internal wheel, which alters the flow of the water and discharges it in a direction parallel to the shaft.

Few of the Niagara turbines are of less than 5,000 h.p.; many develop 10,000 h.p.; and some of the latest 45,000 h.p. Some of the generators which they drive are the largest yet built, weighing 300–400 tons apiece.

The Pelton Wheel, though not employed in the Niagara plants, is widely used in power-stations for coupling to generators where water is available at very high pressures. A wheel consists of a large disk with pairs of cups distributed round its circumference. A jet of water issuing at high velocity from a nozzle strikes the knife-like division between a pair of cups, and is split right and left into two streams which pass round the inside of the cups, and by reversing their direction in doing so impart all their energy to the cups, which travel forward at half the speed

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AN ELECTRIC "FLIER" CROSSING THE "ROCKIES"

The illustration above shows one of the crack express trains, the "Olympian" of the Chicago, Milwaukee, and St. Paul Railway, being hauled by an enormous electric locomotive over the highest point that the track reaches in the Rocky Mountains, Montana. The locomotive would hardly be distinguishable at a distance from the cars, but for the two large "pantographs" which pick up current from the overhead conductor. The electric locomotives used on this system over 650 miles of track are the most powerful haulers yet made, being able to work 3,200 ton loads up a 1 per cent. grade at 16 miles per hour.

IN THE CANYON OF THE JEFFERSON RIVER, MONTANA

A view of part of the electrified section of the Chicago, Milwaukee, and St. Paul Railway in the Rocky Mountains. This line passes through three great mountain ranges on the way—the Rocky Mountains, the Bitter Root Mountains, and the Cascade Mountains—the greatest altitudes attained being 5,768 and 6,322 in the first, 4,159 feet in the second, and 2,564 feet in the third of these ranges. Trains of enormous weight are taken over the summits with ease by the powerful electric locomotives employed.

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SIDE VIEW OF ELECTRIC LOCOMOTIVE HAULING PASSENGER TRAIN

The introduction of the electric locomotive for haulage benefits travellers greatly by abolishing the smoke and dirt inseparable from steam locomotion. In other respects this class of locomotive has some very notable advantages over its older rival. It is ready to start at a moment's notice. It will draw twice as heavy a load at a higher speed, at a greatly reduced cost. Low temperatures increase instead of diminishing its efficiency. It does away with the need for fuel and water stations, tenders, and fuel trains. It requires very little attention, and will run for thousands of miles with only occasional inspection. The locomotive shown develops 3,500 h.p.; weighs 250 tons; and will haul a 960-ton train up a 2.2 per cent. grade at 25 miles per hour. On a straight, level track it can move the same train at 65 miles per hour.

of the jet. The most remarkable Pelton Wheel plant is probably that at Fully, Switzerland. Water is here led downwards from a lake through a pipe three miles long, which in its short course sinks more than a mile—say, through six times the height of the Eiffel Tower—so that at the lower end the pressure in the pipe exceeds a ton per square inch! The water leaves the nozzle at a speed of nearly 400 miles per hour, and, though the wheels are 12 feet in diameter, revolves them 500 times per minute. It may be mentioned in passing that the resistance offered by rapidly moving water to any attempt to deflect its course is remarkable. A jet 3 inches in diameter emerging under a pressure of 500 lb. per square inch cannot be cut through by a blow with a crowbar.

Steam Turbines

In steam-operated power-stations, where the larger part of the electrical energy used by man is still generated, the steam turbine, coupled direct to a generator, is the counterpart of the water turbine.

A steam turbine of the Parsons type consists of a long closed horizontal drum mounted on a shaft in a strong casing, through the ends of which the shaft passes. The annular clearance space between the drum and casing increases by stages, as the latter is "stepped," and this space is filled by rows of curved blades, alternate rows being attached to the drum, and those between them to the casing. The tips of the drum blades just do not touch the casing; while those on the casing just clear the drum and the other blades. In a large turbine there may be some hundreds of thousands of blades, of lengths ranging from an inch to over a foot. Steam is admitted at the smaller end of the casing and threads its way through the many rows of guide and moving blades, every one of the last getting a sideways push which is transmitted through drum and shaft to the generator. After expanding greatly the steam escapes to the condenser either

direct or after doing further duty in another turbine. A turbine is so well balanced and revolves, a thousand times or more per minute, so smoothly, that a coin stood on edge on the casing is not upset.

§ 7

Importance of Water-Power

The scale on which the world's water-powers have been explored and developed during the last ten years is one of the most significant engineering features of the decade. Three times as much water-power is used now as was used ten years ago. The advance has naturally been most rapid in those countries which have depended in the past for their power largely on imported fuel—where "white coal" may be substituted for black. Thus, France has added 850,000 h.p. to the 750,000 h.p. of 1915; Switzerland now has some 1,500,000 h.p. as compared with 850,000 h.p. in 1914; the output in Spain is 900,000 h.p. as against 150,000 h.p. before the war, and that country is engaged on a scheme for developing a further 2,000,000 h.p. The same kind of story may be told of Canada, the United States, Italy, Japan, Norway, Sweden, and India; where also the water turbine is rapidly altering industrial conditions, despite the liberal coal deposits in some of those countries.

The world's total potential water-power has been calculated at 200 million h.p. Estimates must be accepted with reserve, as the surveys have necessarily been very incomplete in the almost unexplored regions where ultimately some of the greatest developments may be expected. So far only 25,000,000 h.p. of this energy has been turned to account. Even at this stage, however, the economies resulting from harnessing water-power are apparent. In the best steam plant of large size 9 tons of coal must be burned to give one horse-power continuously for a year. Therefore 225,000,000 tons of coal, or approximately the

whole output of our coal-mines per annum, represent the amount that would have to be fed to boilers to produce the energy of water already doing service. The world's total water-power would on this basis exceed that obtainable from the world's coal output in 1913!

It may be that the development of water-power will in the future affect the centre of gravity of the world's industries, for these tend to move towards cheap power. A rather interesting illustration presents itself. In North Sweden are vast deposits of iron ore, formerly mined for smelting in England and other coal-producing countries. But Sweden, though poor in native coal, is rich in water-power, now being developed to run great electric furnaces in which the ore will be converted into iron and steel, thus enabling her to compete in the world's markets under favourable conditions. Her waterfalls have given Norway a new industrial importance. Who shall say that a country like Brazil, with its estimated 26,000,000 h.p., and British Guiana, the Zambesi Basin, New Zealand, and other naturally favoured countries, may not in future years become industrially important, thanks to the energy of falling water?

§ 8

Electric Lighting

It is unnecessary to discuss what we owe to electricity in the form of light; it is evident to every one. If an electric current be forced through a very fine wire able to stand extremely high temperatures without melting, the resistance encountered causes the generation of heat, which is partly converted into that form of energy called light. In this way we get the incandescent electric lamp, which is simply a fine wire of tungsten enclosed in a glass bulb, from which all the air is exhausted to prevent the metal being burnt by combination with oxygen, the wire being made white-hot by the current. We may admit, after

exhaustion, a little inert gas which has no effect on the filament; the lamp is then known as gas-filled. Adding the gas makes the lamp more economical, since it gives considerably more light per unit of current consumed, and this is why the gas-filled lamp, made in strengths up to several thousand candle-power, has largely replaced the arc lamp. In an arc lamp two carbon pencils, connected with the circuit, are brought together point to point. The tips become white-hot, and if they now be separated slightly, atoms of incandescent carbon leap across the gap, from one tip to the other, in a continuous and intensely luminous stream, which is called an arc, because the path of its particles is curved. An arc lamp includes apparatus which automatically keeps the pencils the correct distance apart as they burn away; allows them to fall together when the current is switched off; and draws them apart to start the arc when current is switched on. Though more troublesome than the incandescent filament lamp, the arc can be much more powerful; and, as its light proceeds from a very small area, the rays may be accurately focussed by lenses and mirrors and projected in an intensely luminous beam, such as is required for searchlights and cinema projectors. Arc lights of up to 90,000,000 candle-power are used in light-houses. There was, and perhaps still is, at a station on the Jungfrau Railway a lamp that projected a beam visible for sixty miles, which enabled a newspaper to be read in the streets of Thun, thirty-five miles away.

Though, where current is cheap, electric is the cheapest possible form of artificial lighting, besides being far the most convenient, from a scientific point of view it leaves much to be desired. About nineteen-twentieths of the current that produces it is dissipated as heat; and where it depends ultimately on coal, only about one part in a hundred of the coal's energy is converted into light. It has been said that if we could convert energy into light as economically as the glow-worm, a single boy turning a handle could light a fair-sized town. There are evi-

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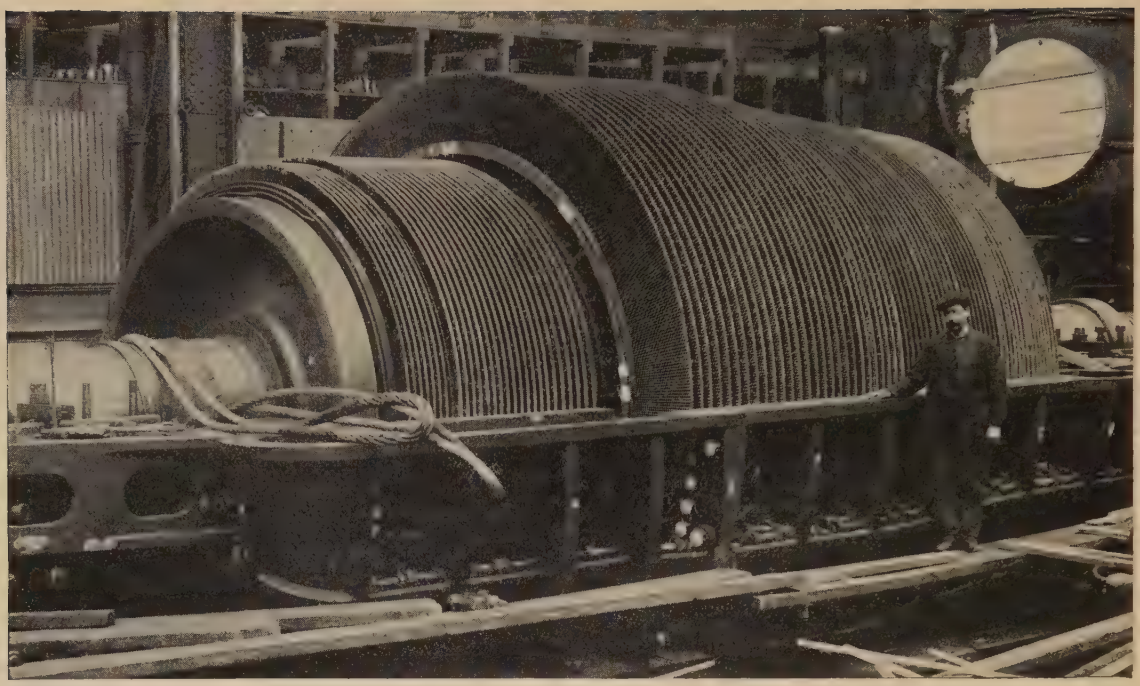
NIAGARA FALLS AS VIEWED FROM THE AIR

The quantity of water passing over these magnificent falls averages 275,000 cubic feet per second, and its energy 6,000,000 horse-power. The falls have already been "tapped" to the extent of 500,000 horse-power, to furnish electric current to an area equal to that of the British Isles. When works already in hand are completed, this total will be doubled.

The greatest of all water-power schemes yet inaugurated connects the Welland River, which enters the Niagara River above the Falls, by means of a long canal running through Canadian territory with a huge power-house at Queenston, several miles below Niagara. In this way a drop of 305 feet is secured, as compared with one of about 150 feet at the Falls themselves.



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THE ROTOR OF A PARSONS STEAM TURBINE

The steam turbine has replaced the reciprocating or piston steam-engine in electrical power-houses, as it can be connected directly to the generators and driven at very high speed without vibration. This illustration shows a turbine with the upper half of the casing removed, leaving the rotor or revolving part exposed. A huge number of blades project in rows from the rotor, like the bristles of a circular brush. These alternate with rows of similar fixed blades projecting inwards from the casing. As the steam passes from one end of the casing to the other, through the space between casing and rotor, it is repeatedly directed on to the moving blades, and its pressure imparts rapid rotation to the rotor.

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ELECTRIC INCANDESCENT LAMPS

The electric incandescent lamp contains a metal wire, the ends of which are led out to exterior plates in the top so that they may be connected with the lighting circuit. Electric current endeavouring to pass through the wire meets with great resistance, which causes the filament to become white-hot and intensely luminous.

The lamp on the left has a very long, thin wire wound up and down over wire spiders projecting from a central glass stem. The bulb is exhausted of air through the tip before being sealed, and the absence of air prevents the wire being burned up. The lamp on the right has a much shorter wire forming part of a circle; the bulb in this case contains some gas which has no effect on the filament. The "gas-filled" is considerably more efficient than the other type; and in its larger sizes is now much used instead of arc lamps for street lighting.

dently great fields still to conquer in the realm of electric illumination.

Electric Heating

For heating purposes electricity is much more efficient, since electrical energy is only too willing to change into heat. One of the difficulties associated with large electrical apparatus is that of keeping parts cool enough to prevent insulation being burned away. Domestic electrical heating appliances derive their heat from wires or very thin films of metal or other suitable material through which current is passed in sufficient strength to make them glow. Some electric radiators are practically the same as incandescent lamps in design and construction; others, again, are mere wires wound on refractory material, and exposed to the air. Electric irons, hot-plates, kettles, etc., have the conductor embedded in mica or asbestos, in close contact to a metal cover, through which the heat is conducted to the matter to be heated. There are very few cooking or heating operations that cannot be performed electrically. So that we now have, besides electric ovens and hot-plates, electrically heated soldering apparatus, glue-pots, foot-warmers, cigar-lighters, bed-quilts, and so on. The aeroplane pilot, soaring many thousands of feet above the earth, would often be paralysed by the intense cold but for the meshwork of insulated wires hidden in his gloves and other clothing, which distributes a grateful warmth due, when traced back to its source, to a small propeller driving a dynamo.

Only a comparatively small part of the electrical energy that is purposely converted into heat is used for domestic purposes, however. Vast quantities of electrical power are now generated for heating furnaces in which are produced all the aluminium we use, all the calcium carbide from which acetylene gas is made, all artificial abrasives, and certain fertilisers containing nitrogen stolen from the atmosphere. Electrical furnaces

now smelt iron and convert it into high-quality steels by the hundred thousand tons. The furnaces are in principle enlarged editions of the arc lamp and domestic "resistance" heater; and all taken together they consume millions of electrical horse-power continuously.

A very important branch of electric heating is that concerned with welding. The electric current has given the engineer an invaluable ally when dealing with repairs to heavy machinery. A typical instance of its helpfulness is supplied by what happened during the war when enemy vessels, interned in American ports, had their boilers and engines rendered useless before abandonment. Under old conditions the only remedy would have been to replace the injured parts by new ones; but with the aid of the electric arc it was possible to unite the edges of broken pieces, and affix patches so securely as to render broken machinery as good as new in effectiveness, if not in appearance. The result was in a very short time many large ships that the enemy regarded as definitely *hors de combat* were ploughing the seas again and doing useful service.

The electric weld is replacing the rivet in many manufacturing processes. The steel plates of a ship's skin may now be joined without the use of a single rivet; and "welded" vessels are actually in commission. Many articles of everyday use are electrically welded. To make a "spot" or local weld, the parts to be joined are pressed together between the points of bars connected with an electric circuit, and the heat set up by the current causes the parts to fuse and amalgamate over an area between the bars. Again, suppose a short bar has to be affixed to a thick plate, to project from it. Instead of drilling a hole in the plate, tapping a thread in it, and cutting a thread on the bar, the last is merely pressed against the plate, and a powerful current passed through both parts; and in a few minutes the two are practically one.

BIBLIOGRAPHY

Bell, *Electrical Power Transmission.*
Fleming, *Fifty Years of Electricity.*
Gibson, *Electricity of To-day.*
Glazebrook, *Electricity and Magnetism.*
Hobart, *Electric Motors.*
Kapp, *Electricity (Home University Library).*
Lodge, *Electrons, or The Nature and Properties of Negative Electricity.*
Walmsley, *Electricity in the Service of Man.*